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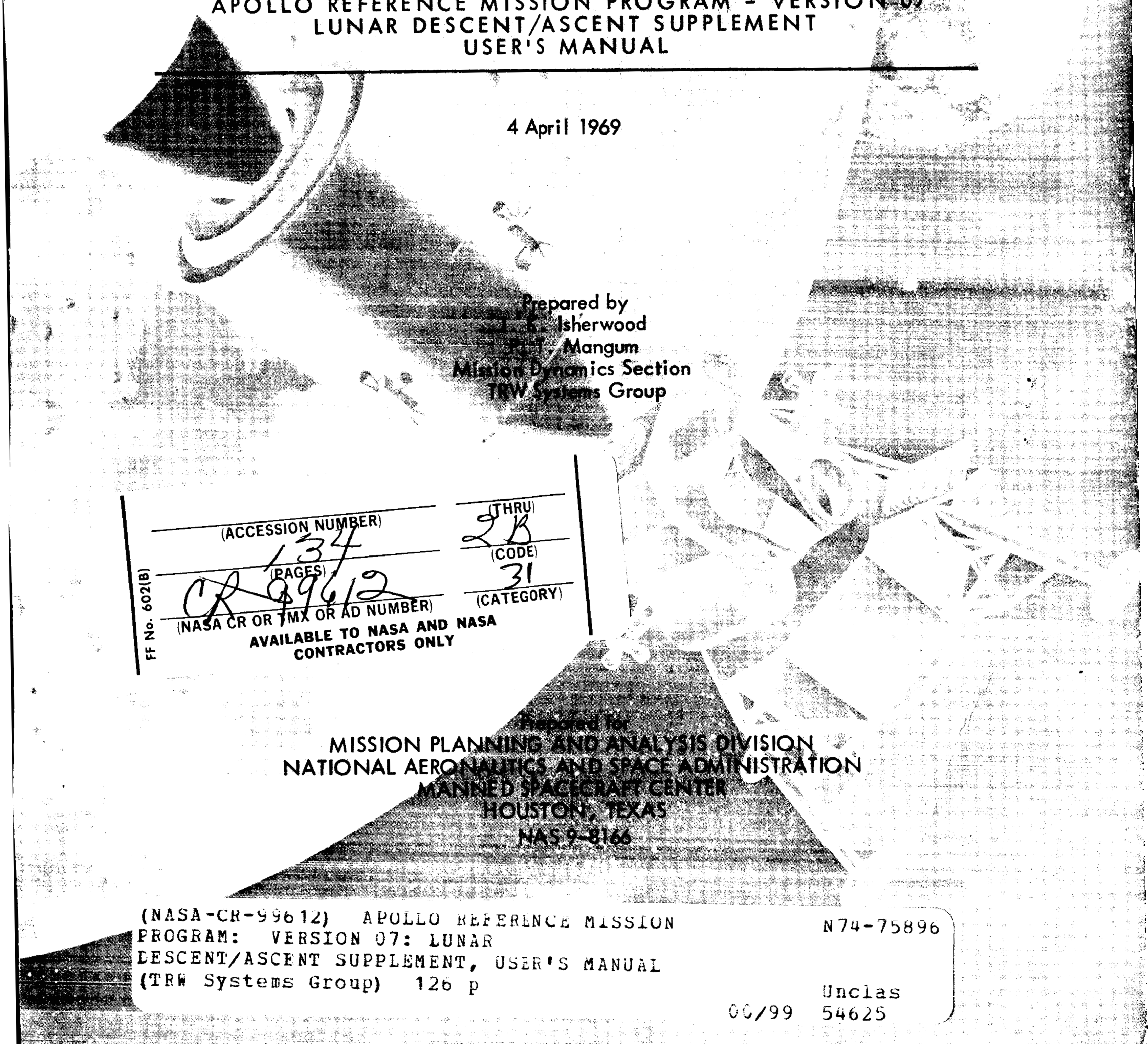
PROJECT APOLLO

TASK MSC/TRW A-215

APOLLO REFERENCE MISSION PROGRAM - VERSION 07 LUNAR DESCENT/ASCENT SUPPLEMENT USER'S MANUAL

4 April 1969



Prepared by
J. K. Isherwood
P. T. Mangum
Mission Dynamics Section
TRW Systems Group

Prepared for
MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS
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Approved by P. T. Mangum
P. T. Mangum, Task Manager
MSC/TRW Task A-215

Approved by E D Stuckle
E. D. Stuckle, Manager
Manned Missions Programming
Department

Approved by D P Johnson
D. P. Johnson
Assistant Project Manager
Mission Design and Analysis
Mission Trajectory Control Program

TRW
SYSTEMS GROUP

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This program was developed for the Landing Analysis Branch, Mission Planning and Analysis Division by TRW Systems Group.

F. V. Bennett, Chief
Landing Analysis Branch

J. H. Alphin, Task Monitor

J. D. Payne, Task Monitor

The following TRW personnel made significant contributions to the development of this program:

V. V. Asbedian
F. D. Cooper
F. E. Gerth, III
K. W. Krause
D. F. McCabe

ABSTRACT

This report is submitted to NASA/MSC by TRW Systems in accordance with the documentation requirements of Task MSC/TRW A-215, "Support for Lunar Descent and Ascent Reference and Operational Trajectory Preparation," Contract NAS 9-8166. This volume contains a description of the descent/ascent capability added to the Apollo Reference Mission Program Version 07 and the input and output specifications necessary for the use of this program.

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TABLES

1. INTRODUCTION

This document provides instructions for the use of the Task A-215 Version of the Apollo Reference Mission Program (ARMP) Version 07. The A-215 program was primarily designed for use as a three-degree-of-freedom (3-D) simulation of the ascent and descent phases of the G mission lunar landing. In addition to providing all of the standard ARM07 capabilities (Reference 1), the A-215 Version of the ARMP includes the following:

a) LM descent guidance (LUMINARY I)

b) LM ascent guidance (LUMINARY I)

c) LM powered-flight steering (LUMINARY I cross product steering) and targeting

d) Descent orbit injection (DOI) targeting

e) Descent/ascent RTCC displays

f) LM AGS (FPX orbit insertion, external delta-V, CSI, CDH, TPI)

The purpose of this document is to provide a supplement to the ARM07 User's Manual. Only those inputs and outputs which have been changed or added are provided in this document.

2. DESCRIPTION OF THE PROGRAM

A general description of the added A-215 program capability is given in this section. The description covers broad program capability rather than detailed subroutine description. The purpose of these program descriptions is twofold. First, they aid in obtaining an understanding of the simulation capabilities and limitations of the A-215 program. Such knowledge is essential in program usage and in evaluating the output. Second, the descriptions aid in understanding the total program.

The descriptions are separated into the major areas of Primary Guidance and Targeting, Descent Orbit Injection Targeting, Descent/Ascent RTCC Displays, and Abort Guidance System.

2.1 PRIMARY GUIDANCE AND TARGETING

In the LUMINARY Program, the FINDCDUW routine is the interface between the guidance program and the LM digital autopilot (DAP) for all powered maneuvers. The primary inputs to the routine are the desired thrust direction vector ($\underline{U}_{FDP}$) and the desired window pointing vector ($\underline{U}_{WDP}$). $\underline{U}_{FDP}$ determines the direction in which the LM thrust vector should be pointed, and $\underline{U}_{WDP}$ provides a basis for attitude orientation of the LM around the thrust axis such that $\underline{U}_{WDP}$ is contained in the plane of the LM X- and Z-axes. The primary outputs from the routine are the gimbal angle increments ($\delta \underline{g}_D$); the desired vehicle angular rates about the X-, Y-, and Z-axes of the LM ($\underline{W}_{DV}$); and the desired attitude lag angles (Φ) by which the LM attitude will lag behind the attitude angle commands due to the finite angular accelerations of the LM.

2.1.1 LM Powered Landing Guidance and Radar

The primary function of the LM Powered Landing Guidance and Navigation Program is to compute the ignition time and thrust level for the descent propulsion system (DPS) and communicate attitude commands to the LM DAP as functions of the navigated LM state vector and the input aim conditions. In addition, various parameters required for display and astronaut monitoring are computed.

The program is divided into five phases according to the trajectory objective to be performed. The first phase is the preignition phase. Its primary function is to compute the time of DPS ignition and initial vehicle attitude. The ullage and trim phase consists of the updating of the LM state vector and the desired landing site during the RCS ullage burn and the DPS, 10 percent thrust, trim burn. The braking phase consists of execution of steering equations to generate attitude and thrust-level commands to achieve a desired aimpoint called HIGATE. The visibility phase is similar to the braking phase with the additional requirement that the landing site be visible for part of the phase to provide landing site redesignation capability for the astronaut. The final phase is called the final descent phase. Its function is to provide steering and thrust commands which reduce the final rate of descent to a constant. Each of these phases is discussed in greater detail in the following paragraphs.

The preignition phase is initiated with a post-DOI, free-fall LM state vector. This vector is expressed in the basic reference inertial coordinate system (BRICS), which, in this program, is the moon-centered inertial coordinate system. The state is then integrated forward to the nominal full throttle position (FTP) time via the coasting integration routine. The updated state vector is then transformed to the stable member or platform coordinate system (PCS) and finally to the guidance coordinate system (GCS). The GCS is an orthogonal Cartesian coordinate system with the X-axis directed along the radius from the center of the moon through the landing site. The Y-axis is defined so that the velocity, acceleration, and jerk (rate of change of acceleration) vectors at the target lie entirely in the X-Z plane, and the Z-axis forms a right-handed system. The GCS is centered at the landing site and rotates about an axis parallel to the moon's polar axis at the nominal time of ignition with an angular rate equal to the mean rate of rotation of the moon.

A test quantity is generated as a function of the difference between the nominal LM ignition position and the updated position and a function of the difference between the nominal ignition speed and the updated speed, all expressed in the GCS. This test quantity, which represents a position to be gained, is divided by the present velocity to determine the increment to be added to the FTP time to obtain a better state at which to initiate the braking phase. If the increment is greater than 0.08 second, an iteration is performed to conically update the LM state vector to the new FTP time and to obtain the new landing site via a rectangular integration of the moon's mean angular velocity. Then a new test quantity is computed as a function of the new guidance state vector. If the iteration converges, the ullage initiation time and the desired vehicle attitude are computed prior to initiation of the next phase, and the LM permanent state vector is integrated forward to the ullage time. Prior to RCS ignition, the vehicle is aligned to the desired attitude.

The only guidance equations executed during the ullage and trim phase are the navigation equations. The state vector update and landing site updates are performed entirely in the PCS. Rectangular integrations are performed over the 2-second guidance cycle time for the LM position vector and the landing site. Point-mass gravity acceleration is then computed as a function of the LM position. Finally, the LM velocity is updated via addition of the sensed velocity increment and a trapezoidal integration of gravity acceleration. In addition, the mass of the LM is updated by decrementing the estimated propellant mass burned over the last guidance cycle.

The ullage burn consists of igniting the RCS aft jets for 7.5 seconds to cause the propellant to settle in the DPS tanks. The trim burn is defined as a 26-second burn of the DPS engine with its throttle set to 10 percent of its maximum capability. The thrust vector attitude command is constant throughout the phase.

The braking phase is initiated with maximum DPS throttle setting of 92.5 percent of maximum rated thrust. The objective is to achieve a HIGATE aimpoint from an initial altitude and speed of about 50,000 feet and 5,600 feet per second, respectively. Evaluation of the guidance loop begins with the navigation update of the LM state vector. The update is similar to that performed during the preceding ullage and trim phase except that below a certain altitude (nominally 35,000 feet), the landing radar is used to provide slant-range measurements to the landing site. These are differenced from the estimate and incorporated through a weighting function to provide a correction to the LM position vector. When the LM velocity drops below 2000 feet per second (nominally), the landing radar is used to provide relative velocity measurements. These are differenced from their respective estimates and incorporated through a weighting function to provide LM velocity corrections. The update of the landing site is identical to the procedure used in the ullage and trim phase.

The desired thrust direction and magnitude during the braking phase are computed according to a quadratic steering equation. The total desired acceleration is a quadratic function of the inverse of the time remaining to HIGATE, t_{GO}, where the coefficients are functions of desired values of LM position, velocity, and acceleration and present values of position and velocity, all expressed in the GCS. Then, after transforming to the PCS, the acceleration due to gravity is subtracted, resulting in desired thrust acceleration. The t_{GO} is computed using a Newton iteration procedure with the derivative expressed as a ratio of polynomials which are functions of t_{GO} and desired downrange components of desired position, velocity, acceleration, and jerk and present values of downrange position and velocity. One phasing option initiates the visibility phase when t_{GO} becomes less than 62 seconds. The alternate phasing option causes the following to occur. During the last 20 seconds, t_{GO} is simply decremented by the guidance cycle time. In addition, the total desired acceleration is computed as a linear function of t_{GO}, where the coefficient is the desired value of jerk at HIGATE and the constant term is the desired HIGATE acceleration. Once the desired thrust acceleration magnitude is computed, it is multiplied by the current estimate of mass to obtain a desired thrust level. The commanded thrust level is equated to desired thrust level if the desired thrust is between 10 and 55 percent. If the desired thrust is less than 10 percent or greater than 63 percent, the commanded thrust level is set to 10 percent or 92.5 percent, respectively. If desired thrust is between 55 and 63 percent, the command thrust is set to the desired or 92.5 percent according to whether the previous thrust command was in the linear region or FTP, respectively. This "hysteresis" effect is to prevent successive large increments and decrements in throttle level. The throttle increment is computed by differencing the commanded thrust level and the average sensed thrust over the last guidance cycle.

The desired attitude of the spacecraft during the braking phase is not determined by the desired thrust direction alone. The body coordinate system (BCS) of the LM is defined as follows: the X-axis is the axis of rotational symmetry, nominally in the thrust direction, and is called the yaw axis; the Z-axis is "forward" from the astronaut's viewpoint, is parallel to the landing window pointing vector, and is called the roll axis; the Y-axis is defined according to the rule of a right-handed orthogonal coordinate system and is called the pitch axis. At the initiation of the braking phase, the window pointing vector or Z-axis is approximately downward along the LM position vector, and the thrust or X-axis is pointed "uprange". As the braking phase continues, the thrust direction starts to pitch up, rotating the window pointing vector toward an uprange direction. At about 35,000 feet, a manual 180-degree yaw maneuver is executed to point the window in a direction to allow the landing radar beams to intersect the moon. After 30,000 feet, the guidance attitude computations attempt to maintain the landing radar window in the plane determined by the LM position vector and the line of sight to the designated landing site. In addition, a desired vehicle angular rate is computed in the VCS as well as a lead-angle vector. These are transmitted to the DAP for control.

The guidance for the visibility phase is very similar to the braking phase. The navigated state is updated by the same procedure. The same quadratic steering is used until the last 10 seconds of the phase when a linear function of t_{GO} is used. At the beginning of the visibility phase, the aim point is redesignated to LOGATE altitude and velocity values of approximately 77 feet and -3 feet per second along the GCS X-axis. The visibility and braking phases use the same equations to achieve the required vehicle attitude to accomplish required thrust and window pointing directions. During the visibility phase, the landing site must be visible to the astronaut for a minimum of 75 seconds. Up until the last 20 seconds of the phase, he is able to redesignate his landing site in two directions perpendicular to his line of sight to the old landing site by use of a hand controller.

The steering equations in the final descent phase are different from those used in the visibility phase, although the navigated state is updated exactly as previously described for the visibility and braking phases. The objective is to achieve and maintain a constant rate of descent to the landing site of 3 feet per second. T_{GO} is not computed. In addition, the GCS is not updated as it was in the previous phases. Also, no computation of yaw error caused by a landing window pointing error is made. Other attitude computations are the same as the visibility and braking phase.

During the early part of the landing maneuver, only platform accelerometer measurements (PIPA pulses) are used to update the LM state vector. When the estimated LM altitude has dropped below 35,000 feet, range measurements (altitude) from the landing radar (LR) are used to update the state at 2-second intervals. When the estimated LM velocity has dropped below 2000 feet per second, velocity-component measurements are processed in addition to the range measurement. The time between consecutive processings of the same velocity vector is 6 seconds. It is important to note that the LR velocity-component measurements, in general, will not be taken at precisely the times that the PIPA outputs are processed. A delay of 1.6 seconds may be simulated by an input option.

State-vector updating, however, is done only at the PIPA-processing times. This, then, requires that the difference between the LR-measured velocity and the estimated values of velocity at the measurement time be carried forward to the next PIPA-processing time for use in the state-vector updating procedure.

The LR routine is called by the descent guidance routine. All four LR outputs are inputs to guidance, where they are used for state-vector updatings.

The vehicle state parameters are measured by four doppler signals that are transmitted to the surface in a fixed-beam pattern relative to the LR plate. Beams 1, 2, and 3 are the velocity measuring beams,and beam 4 is the altimeter beam. During the 8-second period when the antenna is being rotated from position 1 to position 2, the guidance will not call the LR routine, and there is no LR updating of the navigated state.

The slant range of each of the four LR beams is computed and used to determine the noise and bias values corresponding to the range measurement for beam 4 and to the doppler velocity measurements for beams 1, 2, and 3. The errorless values of slant range are input in calculating the individual beam dropout boundary values. The altimeter beam slant range is also used to update the PGNCS estimated state after it has been adjusted to reflect the effects of the lunar terrain. All calculations of slant range are made from the center of gravity of the LR plate.

An important source of error in the use of LR measurements is the uncertainty or variation in the characteristics of the lunar terrain. Of particular concern is the difference in altitude between the selected landing site and the point to which the range measurements are made. This altitude difference or terrain variation is the quantity used to correct the beam slant range.

The basic model selected to represent the lunar terrain is a table lookup which is a function of two variables. Since the table lookup routine is completely general, the user can use any of the variables (up to a maximum of five) to which the table lookup routine has access. A three-dimensional model, defined as a function of an azimuth angle and surface range, would appear to be adequate.

Although it is difficult to model the doppler radar in sufficient detail to account for each of its errors explicitly, a relatively simple model that is representative of radar performance can be used to model radar errors under the following assumptions:

a) The random error is the product of the noise error and a random number (Gaussian distribution with variance 1 and mean 0).

b) The bias error corresponds to the uncertainties in the knowledge of the orientation of the radar-antenna coordinate frame with respect to the inertial reference frame.

Since the LR antenna orientation is fixed with respect to the LM body axes, large angular rotations of the LM could result in a loss of the radar signal. When this happens, there is no radar information available for updating. To include the effects of radar data loss into the simulation, the dropout boundary value is determined using the MSC model developed by G. L. Carman. It is possible to suppress the model leaving the dropout value undetermined.

The MSC LR operating boundary model is simplified from more detailed mathematical models. The boundaries defined are presented as functions of four variables:

- The velocity along the beam
- The range along the beam
- The beam incidence angle (measured from the local vertical)
- The magnitude of the total velocity vector

The curves defined by these functions are the dropout boundaries; i.e., radar tracking will be lost when the boundaries are exceeded. After track has been lost, reacquisition boundaries different from the dropout boundaries are considered. There are two criteria in the MSC model that have to be satisfied before track is reestablished:

a) The beam incidence angle must be 2 to 4 degrees less than the dropout value.

b) A 12-second time delay after the incidence angle becomes 2 to 4 degrees less than the dropout value.

2.1.2 LM Ascent Guidance

The description below is taken mainly from Reference 2. The objective of the LM ascent guidance is to control the LM ascent maneuver to an injection condition so that a specified velocity vector is achieved at a desired radial and crossrange position. The specified injection altitude is with respect to the launch site radius vector magnitude, and the controlled injection crossrange or lateral position is relative to the CSM orbital plane. In order to control the ascent maneuver to these three velocity and two position injection constraints, an explicit guidance concept is used which employs a linear control form. Since this guidance program is used with a fixed thrust engine, the velocity and position condition along the radial and crossrange directions are explicitly controlled by two orthogonal thrust acceleration components varying linearly with time, while the third component of thrust acceleration is determinate. The desired velocity in the downrange direction is achieved by terminating the thrust at the proper time. The development of the ascent guidance equations is such that the best performance is achieved when the required maneuver is in the downrange direction. In the lunar launch or abort maneuvers controlled by this program, all injection position and velocity parameters are therefore controlled with the exception of the position along the velocity vector, referred to as the downrange position.

The LM ascent guidance can control LM ascent maneuvers initiated from noncoplanar launch conditions to be coplanar with the CSM orbital plane at injection. In addition, the guidance can place the LM in an orbit parallel to the CSM orbital plane at a specified out-of-plane or crossrange distance if the astronaut does not wish to remove all of the launch out-of-plane distance during the ascent maneuver. The program is also designed to achieve ascent injection under some off-nominal APS thrust conditions (e.g., a single APS helium tank failure) and to allow for RCS injection in cases of premature APS shutdown.

The Powered Ascent Guidance Program consists of the following three major phases of operations:

- Preignition phase
- Vertical rise phase
- Ascent guidance phase

The LM ascent guidance is also used to control abort maneuvers initiated during the powered lunar landing maneuver. These abort maneuvers can use either the DPS, APS, or a stated combination of the two to achieve the abort injection conditions.

2.1.3 Powered Flight Steering

In the onboard programs, the velocity to be gained is computed throughout the Lambert Aim Point powered-flight guidance in two ways: extrapolated update and guidance update. The velocity-to-be-gained computation for the external ΔV guidance mode, however, is simpler than that for the Lambert Aim Point guidance mode. Since $\underline{b}\Delta t = \underline{0}$ for the external ΔV mode, its velocity-to-be-gained computation uses only the sensed velocity for the extrapolation in the cross-product steering routine:

$$\underline{v}_G = \underline{v}_G - \Delta\hat{\underline{v}}$$

The velocity-to-be-gained computations for the Lambert Aim Point guidance mode involve the determination of a new $\underline{v}_G$ by processing the Lambert Subroutine via the Initial Velocity Subroutine. A second objective is the computation of a new $\underline{b}\Delta t$ parameter for use by the cross-product steering routine. A new required velocity, $\underline{v}_R$, is also determined for use in the next computation cycle of the velocity-to-be-gained subroutine.

The onboard velocity-to-be-gained subroutines in LUMINARY account for the possibility that the $\underline{v}_G$ computation will not be completed for use during the next 2-second computation cycle. In this case, the $\underline{v}_G$ is extrapolated forward over a 2-second interval by use of the velocity-to-be-gained increment, $\underline{b}\Delta t$, which was just computed, and the last PIPA velocity measurement, $\Delta\hat{\underline{v}}$.

At present, the $\underline{v}_G$ computation employed with the A-215 program does not perform the $\underline{v}_G$ extrapolation for burns employing Lambert Aim Point guidance. The Lambert Subroutine is cycled every pass to compute steering commands in the simulation.

It should be noted that the velocity to be gained, $\underline{v}_G$, derived from the Lambert solution using an offset target vector is modified by the term $\underline{g}_b(t)\ [t - t_{IG}]$. This term is an approximation to the velocity change contributed by the earth oblateness effect. The compensation is computed as the current oblateness acceleration, $\underline{g}_b(t)$, multiplied by the period of thrust application $(t - t_{IG})$ where t_{IG} is the nominal ignition time. This correction is zero for lunar orbits. The objective of this correction is to reduce cutoff errors caused by finite maneuver time effects and to minimize commanded thrust attitude variations during the maneuver. These two effects occur during long maneuvers because, in accounting for earth oblateness effects in the initial targeting programs, it is assumed that an impulsive maneuver will be applied at ignition time. Since a finite maneuver time is required, the precomputed target aim point becomes less accurate as the maneuver progresses. The $\underline{g}_b(t - t_{IG})$ correction is an approximate substitute for a retargeting procedure which cannot be performed during a powered maneuver.

For short duration thrust periods or during the initiation of long duration thrust periods before the thrust has increased above the threshold level, there is no active steering, and the vehicle attitude is held at the prethrust alignment. When active steering is initiated, the time-to-go computation and steering commands are performed. Later in the burn when the computed t_{GO} becomes less than 4 seconds, an engine-off signal is set; and for the remainder of the maneuver, no further computations are made except for v_G updating.

The initial computation of t_{GO} in the LUMINARY Program estimates the velocity to be gained after 7 seconds of ullage. If the DPS is selected, the maneuver time, t_{GO}, is then computed on the basis of 10 percent thrust. If this time is less than 6 seconds, no active guidance steering is attempted; and the vehicle attitude is maintained at the prethrust alignment throughout the maneuver. If the DPS t_{GO} is greater than 95 seconds, normal steering will be allowed to throttle the DPS to FTP after the nominal 26-second 10 percent thrust start and trim phase. If the DPS t_{GO} is more than 6 seconds but less than 95 seconds, the DPS throttle will be inhibited from throttling up after the nominal 26-second trim phase and will remain at 10 percent thrust for the duration of the maneuver. It might be noted that the DPS trim phase duration (e.g., 26 seconds) is an erasable memory parameter and can be modified.

If the APS is chosen, a check is first made to determine if the maneuver time is less than 1 second. If the maneuver time is less than 1 second, the t_{GO} estimate is made on APS minimum impulse test data. In this case, no active steering is attempted. If the maneuver time is greater than 1 second but less than 6 seconds, t_{GO} is computed but no active steering is attempted. If the estimated maneuver time, t_{GO}, for either the APS or DPS is less than 6 seconds, the engine-off signal is set for $t_{IG} + t_{GO}$. If the estimated maneuver time is greater than 6 seconds, active steering is used, and t_{GO} computations are performed during the maneuver. If the LM RCS is chosen for the maneuver, the t_{GO} prediction is not made by the primary steering routine.

2.1.4 Primary Targeting and IMU Alignment Routines

The onboard targeting programs employed for the coelliptic flight plan are coded to operate as specified in Reference 2 (LUMINARY) and consist of the following routines:

a) Coelliptic Sequence Initiation (CSI)

b) Constant Differential Altitude (CDH)

c) Transfer Phase Initiation (TPI)

d) Rendezvous Midcourse (MCC)

All of these routines employ the universal variable conic programs developed by MIT for use with LM and CSM guidance programs. These new routines replace the nonuniversal SUNDISK conic routines. Cross-product steering is used to steer each of the guided maneuvers. In targeting the CSI and CDH maneuvers, the required ΔV is obtained and expressed in local horizontal coordinates. In targeting the TPI and MCC maneuvers, the required biased target vector and flight time for rendezvous of the active vehicle with the passive vehicle are obtained.

In addition to the LUMINARY targeting routines, the Lambert Aim Point targeting is available. The initial attitude and IMU alignment routines specified in Reference 2 are also available in the A-215 Program.

The pre-CSI targeting computes the parameters associated with the CSI maneuver. The astronaut inputs to this program are as follows:

a) Choice of active vehicle

b) Time t_1 of the CSI maneuver

c) Number N of the apsidal crossing. (If N = 1, the CDH maneuver occurs when the active vehicle reaches its first apsidal point following the CSI maneuver, etc.)

d) Desired line-of-sight LOS angle E at the time of the TPI maneuver

e) Time t_3 of the TPI maneuver

The navigated vehicle state vector, $\underline{r}_A$, $\underline{v}_A$, and passive vehicle state vector, $\underline{r}_p$, $\underline{v}_p$, are available in the guidance computer.

The following constraints must be satisfied:

a) The CSI ΔV is applied in the horizontal plane of the active vehicle at the CSI time.

b) The CDH maneuver occurs when the active vehicle is at a specified apsidal crossing.

c) The semimajor axis and radial component of velocity of the active vehicle are such that the active and passive vehicles are in coelliptic orbits following the CDH maneuver.

d) The line of sight between the active vehicle and the passive vehicle at the TPI time forms the elevation angle, E, with the horizontal plane of the active vehicle.

e) The time intervals between the CSI-CDH and CDH-TPI maneuvers are 10 minutes or greater.

f) After both the CSI and CDH maneuvers, the perigee altitude of the active vehicle orbit is greater than 35,000 feet for lunar orbits and 85 nautical miles for earth orbits.

The program solution is based on conic propagation of the vehicle state and contains an iteration loop to select the CSI velocity-to-be-gained magnitude, v_1.

The pre-CDH targeting computes the parameters associated with the CDH maneuver. The astronaut inputs to this program are as follows:

- Choice of active vehicle
- Time t_2 of CDH maneuver

The active and passive vehicle's navigated state vectors, $\underline{r}_A$, $\underline{v}_A$, $\underline{r}_p$, and $\underline{v}_p$, are available in the guidance computer. The TPI elevation angle, E, and the TPI maneuver time, t_3, are also available from the previous pre-CSI program computations.

To perform the computations, the state vectors of both the active and passive vehicles are advanced to the CDH time using the Coasting Integration Routine. After projecting the active vehicle state vector into the plane of the passive vehicle, the CDH maneuver is calculated as in the pre-CSI program. Following a precision update of the state vectors to time t_3, the pre-TPI program is entered to calculate the time at which the specified elevation angle is attained. If the iteration in the TPI program is not successful, an alarm code is displayed. At this point, the astronaut can elect to recycle the pre-CDH program or to proceed with the calculation of the displays. The recycle capability is not included in the A-215 simulation.

The objective of the pre-TPI targeting program is to compute parameters required for the transfer phase initiation (TPI) maneuver. The position of the TPI maneuver is determined by specifying either the TPI time or the elevation angle which specifies the relative geometry of the vehicle at the TPI point. The astronaut inputs are as follows:

- Choice of active vehicle
- Time t of the TPI maneuver
- Elevation angle E (set equal to zero if t is specified)
- Central angle ωt between the passive vehicle at the TPF and TPI points.

The navigated active vehicle ($\underline{r}_{A1}$, $\underline{v}_{A1}$) and passive vehicle ($\underline{r}_{P1}$, $\underline{v}_{P1}$) state vectors are available in the guidance computer. The program starts with a precision update of these vectors to the estimated TPI time. An iteration is performed to determine the exact TPI time at which the input elevation angle is achieved. Upon convergence, the state vectors are precision updated to the exact TPI time.

The TPI-TPF phase of the program starts with the use of the angle ωt in the Time-Theta Subroutine to determine the corresponding transfer time t_F. After precision updating of the passive vehicle through t_F, the Initvel Routine is then called to compute the offset target vector at TPF. The offset target vector, the time of TPI, and the time of intercept are the required guidance input parameters.

The rendezvous midcourse (MCC) targeting program computes a midcourse correction maneuver which insures that the active vehicle will intercept the passive vehicle at the time established in the previous pre-TPI program. The astronaut may call this program any time after the TPI maneuver but, in general, no later than 10 minutes before the intercept time.

For MCC targeting, there is one astronaut input: choice of the active vehicle. The navigated active ($\underline{r}_A$, $\underline{v}_A$) and passive ($\underline{r}_p$, $\underline{V}_p$) vehicle state vectors, the intercept time t_{TPF} (from the pre-TPI program), and a time delay required to prepare for the thrust maneuver are available in the guidance computer. The Coasting Integration and Initvel Routines are employed to update the state vectors and to compute the offset target vector.

The Lambert Aim Point targeting includes the capability to offset the input target vector. The input required for the Lambert Aim Point Routine are as follows:

a) Desired target vector

b) Time of flight from ignition to target vector intercept

c) Number of target vector offsets (usually two or three are sufficient)

The targeting program then computes the offset target vector and makes it available to the guidance steering routines.

The initial attitude routine for external delta V and Lambert guidance accept output from the targeting routines to compute the desired thrusting direction. The unit thrust direction is then employed to specify the desired IMU alignment.

IMU alignment and vehicle orientation options are consistent with those defined for the Apollo mission. Options other than Apollo may be selected as ATYPE options instead of, or in conjunction with, those described in this manual. However, it should be clearly noted that the ARMP A-215 version computes the initial thrust direction as part of the preferred IMU alignment routine. Therefore, it may be necessary to align the IMU in order to get $\underline{U}_T$ for the vehicle attitude orientation then realign the IMU to get the desired IMU alignment. These options are not meant to be general options but are specific options available to the Apollo mission vehicles.

2.2 DESCENT ORBIT INJECTION TARGETING

The descent orbit injection (DOI) capability is designed to simulate the near-lunar LM operations which begin soon after separation from the CSM while the LM is over the planned landing site in a 60 nautical mile circular parking orbit. Nearly one-half orbit later, the LM performs the DOI burn. This Hohmann maneuver is designed to place the LM on an elliptic trajectory characterized by an apocynthion altitude of 60 nautical miles and a pericynthion altitude of 50,000 feet (8.3 nautical miles). Powered descent initiation (PDI) takes place at pericynthion, although the powered descent guidance logic actually controls ignition time. The powered descent guidance logic controls the LM trajectory from an initial altitude of 50,000 feet and an inertial velocity of 5,600 feet per second to the planned landing site with about an 11-minute continuous burn comprising 14 degrees of arc travel.

2.3 DESCENT/ASCENT RTCC DISPLAYS

The RTCC display capability of the A-215 program simulates the various parameters used to monitor the lunar descent/ascent trajectory onboard the LM and on the ground.

2.3.1 RTCC Ground Displays

The RTCC Ground displays are used to simulate the computation of parameters pertinent to the descent/ascent monitoring performed by the Real-Time Computer Complex (RTCC). One of the main functions of the ground displays is to obtain differences between the PGNS state vector and the AGS state vector which are defined in the local vertical coordinate system. Because the AGS state vector will not be identical with the PGNS state vector in most cases, the CSM orbital plane is chosen as a common reference to define the downrange axis in the local vertical coordinate system construction.

The MSFN state vector, which is defined by tracking, is resolved into a similar local coordinate system for computation of differences between the MSFN state vector and the PGNS and AGS state vectors, respectively. The ground displays also compute the differences between the LR altitude and the PGNS and AGS state vectors, respectively. Logic is also provided for the resolution of the PGNS relative velocity into the LR antenna axes, which provides differences between the relative velocities as measured by the LR. Currently, the RTCC has the logic for computing differences only in the Y-axis (crossrange). In addition to computation of differences, the displays are designed to output wedge angle, crossrange velocity, local pitch and yaw angles, and range to go to targets.

2.3.2 RTCC Onboard Displays

The RTCC onboard displays simulate LM cockpit displays of LR data, DPS thrust data, and certain AGS parameters used to verify similar PGNS parameters (see Section 4.2.13.1 for discussion of AGS and PGNS display parameters).

2.4 ABORT GUIDANCE SYSTEM

The abort guidance system routines provide for targeting, guidance, navigation, and desired steering commands for simulation of the orbit insertion, coelliptic sequence initiate (CSI), constant differential altitude (CDH), transfer phase initiate (search and execute) (TPI), midcourse correction, and external ΔV routines. All targeting is performed using state vectors of the LM and CSM propagated to the time of ignition using a closed form of integration (f and g series).

The targeting for the orbit insertion routine is predetermined and is not performed in the AGS. The CSI, CHD, and TPI guidance targeting routines begin by computing the predicted maneuvers prior to the nominal maneuver time and then continue to compute a real-time solution during the actual maneuver. This differs somewhat from the philosophy used in the PGNS CSI, CHD, and TPI targeting routines (which are only cycled once.) Either external ΔV or Lambert steering is used by the PGNS to steer the burn. The AGS uses the external ΔV routine when it is found that there is too large an out-of-the-CSM-plane velocity component at the time of the maneuver. In addition, the external ΔV routine has the capability to issue commands to maintain the vehicle in a prescribed orientation with respect to the local horizontal. This later capability is only operative when the prescribed thrusting information is available, since the AGS does not control the thrusters or thrust level. In the onboard case, the astronaut does all the thrust control for the AGS. The external ΔV can also be used to remove any residual velocity to be gained which remains after a maneuver.

The orbit insertion routine provides attitude commands and engine-off commands to obtain predetermined cutoff conditions such as desired insertion altitude above the lunar launch site, desired magnitude of the horizontal component of inertial velocity at burnout and desired radial velocity at burnout. The orbit insertion routine also provides attitude commands for steering the LM into the CSM plane. The current coding of the orbit insertion routine is updated to that of the flight program X (FPX). This is the only AGS routine in A-215 which has been updated to FPX status.

The CSI routine, which is selected shortly after orbit insertion, computes the horizontal velocity increment required to satisfy the targeting conditions: time of ignition of the CSI burn, desired time of TPI, and desired elevation angle at TPI. The CSI solution is such that, after the CSI and CDH maneuvers, the LM will arrive at the desired TPI time with the desired LOS angle.

The time of ignition for the CDH maneuver is calculated in the CSI routine based upon input that determines if the CDH maneuver will be performed at the first, second, or third crossing of the line of apsides of the LM orbit.

The CSI routine performs an iteration on the horizontal ΔV increment. The routine iterates three times every 2-second cycle and the "best" solution is saved. This best solution is determined by a minimum cost function defined as the absolute value of the difference between the desired central angle and the estimated central angle between the LM and the CSM at the specified TPI time. Although the CSI horizontal ΔV solution is not valid until CSI ignition time, the CSI routine computes valid steering commands after ignition.

The CDH maneuver is calculated so that after the burn the LM will be in an orbit coelliptic with the CSM orbit. The desired LM semimajor axis will be equal to the CSM semimajor axis minus the differential altitude defined as the difference between the CSM and LM orbital altitude at the time of CDH ignition.

The CSI and CDH routines command velocity increments that are essentially parallel to the CSM orbit plane. Therefore, no out-of-plane correction can be accomplished using these routines to steer. If it is found that an out-of-CSM-plane velocity component does exist at the beginning of either of these maneuvers, the external ΔV steering is used to fly the maneuver.

The TPI routine uses a fixed time increment from a specified ignition time to rendezvous to determine the required velocity increment. The state of the LM is determined at ignition by an ellipse predictor routine (closed form f and g series). The state of the CSM is also determined at the rendezvous point by the ellipse predictor routine. Given the position of the LM at the TPI time, the rendezvous position and the transfer time, the routine computes a trajectory which passes through the ignition point and the rendezvous point in the specified transfer time by iterating on the semilatus rectum of the ellipse.

The LM velocity increment required at TPI to place the LM on the intercept trajectory is obtained from the transfer impulse calculations. The braking impulse required for rendezvous is also calculated. There are two options in the TPI direct transfer routine. The first is a TPI search routine which requires a fixed time increment to transfer initiation input. The search routine, which is used for prethrust calculations only, computes a solution based either on acquiring the desired LOS angle or minimizing the velocity to be gained during the maneuver. The second option in the TPI routine is used to execute the maneuver. The converged solution from the TPI search routine is used in the TPI execute routine. If there is a midcourse correction and there is no need to change the point of rendezvous, new entries of ignition time and transfer time are not required.

The calculation of midcourse corrections requires the following restrictions on trajectories being flown:

a) Apocynthion altitude less than 300 nautical miles

b) Eccentricity less than 0.5

c) No transfer within a 10-degree neighborhood of 0-, 180-, or 360-degree central angle transfer

d) No transfer which requires more than 8192 seconds to intercept with the CSM

The ΔV components employed in the External Delta V routine are referenced to the LM local vertical coordinate system. They are specified along the LM local vertical (positive downward toward the central body), in the local horizontal plane (positive in the direction of motion parallel to the CSM plane), and perpendicular to the CSM orbit plane (positive in the direction opposite to the CSM angular momentum vector). If these components are not calculated in the CSI or CDH routines, they must be specified by input.

3. INPUT

The A-215 program is an extension of the Apollo Reference Mission Program (Version ARM07) and employs the same inputs with several additions and exceptions. Therefore, this section will discuss only those inputs which are not included in the ARM07 user's manual, or which have been changed. For a complete list of available inputs, see Reference 1, Section 4.

3.1 INPUT CHANGES FROM ARM07

3.1.1 Changed Inputs

G002 to G0075 — These input symbols have been deleted.

INAV — Flag to specify update and integration routine to compute the navigated state vector (fixed point) (preset to 0). INAV can be input for two vehicles in a manner shown by the following example:

INAV = 1, -2

If no value is input, the navigated state vector will be the dynamics state vector.

- = 0 Navigated state continually equals actual state.
- = +1 Initiate with actual state and use average-g integration.
- = -1 Continue with navigated state and use average-g integration.
- = +2 Initiate with actual state and use onboard Encke integration.
- = -2 Continue with navigated state and use onboard Encke integration.
- = +3 Initiate with actual state and use Runge Kutta integration.
- = -3 Continue with navigated state and use Runge Kutta integration.
- = +4 Initiate with actual state and use descent guidance average-g integration.
- = -4 Continue with navigated state and use descent guidance average-g integration.

= -10 Initiate with input navigated state and use average-g integration.

= -20 Initiate with input navigated state and use onboard Encke integration.

= -30 Initiate with input navigated state and use Runge Kutta integration.

= -40 Initiate with input navigated state and use descent guidance average-g integration.

Note: INAV = -10, -20, -30, or -40 must be accompanied by the data input variables RN1, VN1, and the appropriate value of INJECT.

RN This input has been deleted and replaced by RN1 and RN2 (3.1.2).

VN This input has been deleted and replaced by VN1 and VN2 (3.1.2).

3.1.2 New Inputs (All inputs are floating point unless otherwise specified)

GC001 Breaking phase indicator (3.2.3) (fixed point).

GC002 Guidance option flag (3.2.1, 3.2.2, 3.2.3) (fixed point).

GC003 Landing radar flag (3.2.3) (fixed point).

GC004 Cross-product steering option (3.2.1) (fixed point).

GC005 Guidance and targeting flag (3.2.1) (fixed point).

GC006 Guidance selector (3.2.2) (fixed point).

GC009 CSM state vector selector (3.2.2) (fixed point).

GC010 Delta V vector flag (3.2.2) (fixed point).

GC011 Convergence criteria flag (3.2.2) (fixed point).

GC012 Number of cycles for convergence (3.2.2) (fixed point).

GC013 Guidance option flag (3.2.2, 3.2.3) (fixed point).

GC014 Guidance option flag (3.2.2, 3.2.3) (fixed point).

GC015 Signal-to-noise model option flag (3.2.3) (fixed point).

GC016 Guidance data (3.2.1, 3.2.2, 3.2.3).

GC017 Guidance data (3.2.1, 3.2.3).

GC018 Guidance data (3.2.1, 3.2.2, 3.2.3).

GC019	Guidance data (3.2.1, 3.2.2, 3.2.3).
GC020	Guidance data (3.2.1, 3.2.3, 3.2.4).
GC021	Guidance data (3.2.1, 3.2.3, 3.2.4).
GC022	Guidance data (3.2.3).
GC023	Guidance data (3.2.2, 3.2.3).
GC024	Guidance data (3.2.1, 3.2.2, 3.2.3).
GC025	Guidance data (3.2.2, 3.2.3).
GC026	LR altitude update scale factor (3.2.3).
GC027	LR velocity update scale factor (3.2.3).
GC028	Guidance data (3.2.2, 3.2.3).
GC029	Guidance data (3.2.2, 3.2.3).
GC030	Guidance data (3.2.2, 3.2.3).
GC031	Guidance data (3.2.2, 3.2.3).
GC032	Guidance data (3.2.1, 3.2.2, 3.2.3).
GC033	CDH ignition time (3.2.1).
GC034	Velocity-to-be-gained threshold (3.2.2).
GC035	Guidance data (3.2.2, 3.2.3).
GC036	Orbit insertion targeted insertion altitude (3.2.2).
GC037	Vertical pitch steering altitude threshold (3.2.2).
GC038	Guidance data (3.2.2, 3.2.3).
GC039	Horizontal velocity to be gained (3.2.2).
GC040	Out of CSM plane velocity to be gained (3.2.2).
GC041	Guidance data (3.2.2, 3.2.3).
GC042	Guidance data (3.2.2, 3.2.3).
GC043	Guidance data (3.2.2, 3.2.3).
GC044	Time of landing site redesignation (3.2.3).
GC045	Guidance data (3.2.2, 3.2.3).

GC046 Guidance data (3.2.2, 3.2.3).

GC047 Guidance data (3.2.2, 3.2.3).

GC048 Guidance data (3.2.2, 3.2.3).

GC049 Guidance data (3.2.2, 3.2.3).

GC050 Altitude update value (3.2.2).

GC052 Time at which to check for LR slewing (3.2.3).

GC054 Criterion for LR slewing (3.2.3).

GC055 CSM state vector epoch time (3.2.2).

GC056 CSM state vector position components (3.2.2).

GC057 Desired value of $\underline{R}_G$ for visibility phase (3.2.3).

GC059 CSM state vector velocity components (3.2.2).

GC060 Desired value of $\underline{V}_G$ for visibility phase (3.2.3).

GC063 Desired acceleration for visibility phase (3.2.3).

GC065 Velocity-to-be-gained vector (3.2.2).

GC066 Guidance data (3.2.2, 3.2.3).

GC067 Guidance data (3.2.2, 3.2.3).

GC068 Nominal speed of LM at DPS ignition (3.2.3).

GC069 Damping factor for ignition time iteration (3.2.3).

GC070 LS vertical error scale (3.2.3).

GC071 Cross-range error scale factor (3.2.3).

GC072 Nominal position of LM at DPS ignition Y-component (3.2.3).

GC073 Nominal position of LM at DPS ignition Z-component (3.2.3).

GC074 Guidance data (3.2.2, 3.2.3).

GC075 Guidance data (3.2.2, 3.2.3).

GC076 LS update scale factor (3.2.3).

GC077 Guidance data (3.2.2, 3.2.3).

GC080	Time of TPI ignition (3.2.2).
GC081	Estimate of burn duration (3.2.3).
GC082	Breaking phase time-to-go criterion (3.2.3).
GC083	Visibility phase time-to-go criterion (3.2.3).
GC084	Guidance data (3.2.2, 3.2.3).
GC085	CSI convergence value (3.2.2).
GC086	Maximum thrust capability of DPS engine (3.2.3).
GC087	Response time for the DPS engine (3.2.3).
GC088	Delta time from PIPA reading to thrust command (3.2.3).
GC089	Thrust pulse-train time compensation flag (3.2.3).
GC091	APS impulse velocity constant (3.2.1).
GC092	APS impulse constant at ignition (3.2.1).
GC093	Slope of APS minimum impulse curve (3.2.1).
GC094	10% DPS engine thrust (3.2.1).
GC101	α_1, α_2 antenna plate angles (3.2.3).
GC103	β_1, β_2 antenna plate angles (3.2.3).
GC105	Ω design angles between LR beams (3.2.3).
GC109	Misalignment of LR Ω design angles (3.2.3).
GC113	ξ design angles between LR beams (3.2.3).
GC117	Misalignment of LR ξ design angles (3.2.3).
GC121	Distance between c.g. of LR plate and c.g. of LM (3.2.3).
GC134	Time from precompute to ignition (3.2.2).
GD7VE	Exhaust velocity (3.2.4).
GP02	Guidance option flag (3.2.1, 3.2.2, 3.2.3) (fixed point).
GP03	Guidance option flag (3.2.1, 3.2.2) (fixed point).
GP04	Guidance option flag (3.2.1, 3.2.4) (fixed point).

GP05	Guidance option flag (3.2.1, 3.2.4) (fixed point).
GP06	Guidance data (3.2.1, 3.2.2, 3.2.3, 3.2.4).
GP07	Guidance data (3.2.1, 3.2.2, 3.2.4).
GP08	Guidance data (3.2.1, 3.2.2, 3.2.3, 3.2.4).
GP09	Guidance data (3.2.1, 3.2.2, 3.2.3, 3.2.4).
GP10	Guidance data (3.2.1, 3.2.2, 3.2.3).
GP11	Guidance data (3.2.1, 3.2.2, 3.3.3).
GP12	Guidance data (3.2.1, 3.2.2, 3.3.3, 3.3.4).
GP13	Guidance data (3.2.1, 3.2.2, 3.3.3).
GP14	Guidance data (3.2.2, 3.2.3).
GP15	Upper limit on predicted final LM radial rate (3.2.2).
GP16	Guidance data (3.2.1, 3.2.2, 3.2.3).
GP17	Tangent of desired TPI line-of-sight angle (3.2.2).
GP19	Direction cosines of $\overline{Z}_{IMU}$ relative to ECI (3.2.1).
GP21	Initial mass to mass flow rate ratio (3.2.3).
ISTYPE	Preset guidance constants option (3.2.3) (fixed point).
JNAV	AGS navigation selector (3.2.2) (fixed point).
K21	AGS universal gravitational constant (3.2.2).
LMDVEX	Estimated effective DPS exhaust velocity (3.2.3).
LMMASS	Estimated mass of the LM (3.2.3).
LRAB	LR altitude bias table (3.2.3).
LRAN	LR altitude noise table (3.2.3).
LRELV	LR elevation table (3.2.3).
LRVR	LR velocity bias table (3.2.3).
LRVN	LR velocity noise table (3.2.3).
RALTFT	Descent phase termination altitude (3.2.3).
RNA	Initial AGS navigated position vector (3.2.2).

RN1 Initial navigated position vector of vehicle 1 (3.2.1, 3.2.3, 3.2.4).

RN2 Initial navigated position vector of vehicle 2 (3.2.1, 3.2.3, 3.2.4).

TRIM2 Pitch trim angle (3.2.1).

TRIM3 Yaw trim angle (3.2.1).

VNA Initial AGS navigated velocity vector (3.2.2).

VN1 Initial navigated velocity vector of vehicle 1 (3.2.1, 3.2.3, 3.2.4).

VN2 Initial navigated velocity vector of vehicle 2 (3.2.1, 3.2.3, 3.2.4).

Note: All GCXXX inputs carry over from phase to phase, while all GPXX inputs must be input for each phase in which they are to be used unless the preset guidance constants option (ISTYPE) has been input.

3.2 GUIDANCE INPUTS

3.2.1 LM Primary Guidance System

Input Symbol	Math Symbol	Definition
ALTLS		Elevation of landing site (ISCALE units)
DTGUID	Δt	Incremental step size at which the guidance equations are solved; this value may be input in double precision (hr) If DTGUID is not input, the guidance equations are solved at the thrusting integration step size, as specified by TCINT
GC002		Input flag indicating the coordinate system and source of the initial velocity vector to be input to the external ΔV guidance precompute logic (fixed point) = -1 $\underline{\Delta V}_S$ based upon CSI targeting (This input is no longer required but is set internally.)

Input Symbol	Math Symbol	Definition
		= 0 $\underline{\Delta V}_S$ according to CDH targeting (This input is no longer required but is set internally.) = 1 $\underline{V}_r$ from Lambert's solution in precompute (This input is no longer required but is set internally.) = 2 $\underline{\Delta V}_S$ externally input in local vertical = 3 $\underline{v}_g$ externally input in local vertical = 4 $\underline{\Delta V}_S$ externally input in ECI = 5 $\underline{v}_g$ externally input in ECI where: $\underline{\Delta V}_S$ velocity increment, to be compensated for burn arc $\underline{v}_g$ velocity to be gained, not to be compensated for burn arc Notes: 1) GC002 = -1, 0, or 1 is set internally based upon the appropriate targeting routine entered. 2) GC002 = 2, 3, 4, or 5 must be input within the precompute phase in conjunction with GP13, components of input velocity, and IPTYPE = 2. 3) For DØI targeting, GC002 is internally set to 4 unless GC002 = 5 is input. $\underline{\Delta V}_S$ and $\underline{v}_g$ are computed by DØI targeting with GC002 specifying the following options: = 4 compensate for burn arc = 5 no compensation for burn arc

Input Symbol	Math Symbol	Definition
GC004		Cross product steering option (fixed point) = 0 CSM cross product routine = 1 LM cross product routine
GC005 (Guidance)		Cross product steering flag (fixed point) = 0 Use LUMINARY cross product steering = 1 Use SUNDANCE cross product steering
GC005 (Targeting)		= 0 Use LUMINARY parameters in precompute = 1 Use SUNDANCE parameters in precompute
GC016	c	Cross product steering constant, c, in equation $\underline{q} = c \left[\underline{b} - (\underline{v}_g \cdot \underline{b})\underline{v}_g \right]$
GC017	F	Estimated thrust magnitude at main engine ignition used in the precompute logic to determine the thrust acceleration at ignition or within the short burn logic to determine t_{GO} (lb)
GC018	t_i	Time of ignition referenced to launch time (hr)
GC019	E	Desired elevation angle, measured positive above local horizontal, at TPI ignition (deg). It must be input in the CSI and CDH precompute phases. It is optional in the TPI phase. It cannot be zero in the CDH phase.
GC020		Tolerance on TPI elevation angle used in the iteration on TPI ignition time (deg)
GC021	$\underline{r}_T$	Aim vector for Lambert Aim Point Guidance (ft)

Input Symbol	Math Symbol	Definition
GC024	t_f	Transfer time for Lambert Aim Point Guidance measured from ignition time to desired arrival time at target vector (hr)
GC032	t_3	Desired time of TPI ignition referenced to launch, input to pre-CSI or pre-CDH (hr)
GC033		Ignition time for CDH referenced to launch, input to pre-CDH (hr). Do not use this input if it is computed in CSI precompute
GC091	K1	APS impulse velocity acquired in a 1 second maneuver for a unit mass vehicle $\left(\frac{\text{Kg}\cdot\text{m}}{\text{c sec}}\right)$ (preset 124.544)
GC092	K2	APS impulse constant at the time of ignition t_i $\left(\frac{\text{Kg}\cdot\text{m}}{\text{c sec}}\right)$ (preset 31.136)
GC093	K3	Slope of APS minimum impulse curve $\left(\frac{\text{Kg}\cdot\text{m}}{\text{c sec}^2}\right)$ (preset 1.5568)
GC094	K4	10% DPS engine thrust (lb) (preset 1050.)
GP02 (Guidance)		Indicator which specifies the computation of the velocity-to-be-gained vector, derived from the Lambert solution (fixed point) = 0 The average-g navigated state vector is used in obtaining the Lambert solution = 1 The navigated state vector used in obtaining the Lambert solution is based upon the spherical gravitation model $g = -\frac{\mu}{r^2} r$.

Input Symbol	Math Symbol	Definition
		= 2 The velocity-to-be-gained vector, $\underline{V}_g$, derived from Lambert's solution is modified by the oblateness term g_{OBL} That is, $\underline{V}_g = \underline{V}_r - \underline{V} + g_{OBL}\,(t - t_{ig})$ This term is an approximation to the velocity change contributed by the earth oblateness effect
		= 10 Velocity to be gained is carried to the phase GP02 is input
GP02 (Alignment)		IMU alignment or vehicle attitude orientation flag (fixed point)
		= 0 Orientation and alignment will occur at same time
		= 1 IMU alignment only
		= 2 Vehicle attitude oriented to current IMU alignment
		= 3 Vehicle attitude orientation only
		Note: GP02 must be accompanied (in same phase) by IPTYPE = 3, and possibly GP03 and GP04 (refer to these definitions)
GP03 (Guidance)		Powered-flight steering flag that indicates method to be used to compute required velocity, $\underline{V}_r$ (fixed point)
		= 0 External ΔV
		= 1 Lambert
GP03 (Alignment)		Indicator which specifies the trim angles to be used in the IMU preferred or exact alignment computations (fixed point)
		= 0 Alignment will be performed based on the input values of TRIM2 and TRIM3 only

Input Symbol	Math Symbol	Definition
		= 1 Alignment will be performed based upon the vehicle's mass properties; i.e., c.g. location, main engine's gimbal point location, and user inputs TRIM2 and TRIM3
		= 2 Alignment will be based upon the last value of the previous main engine gimbal angles (β_2, β_3) and inputs TRIM 2 and TRIM3
		Notes: 1) In accordance with the onboard LM preferred alignment procedure, the user should use the inputs GP03 = 0, TRIM2 = 0, and TRIM3 = 0 within the ARMP LM IMU preferred alignment phase.
		2) GP03 must be input in conjunction with IPTYPE = 3, GP04 = +1 or +2, and possibly (user's option) TRIM2 and TRIM3.
		3) GP03 = 1 must be accompanied by GIMPT and the vehicle's mass characteristics input data.
GP03 (Targeting)	N1	Number of times GC021 is offset (fixed point)
GP04 (Guidance)		Short burn logic indicator (fixed point)
		= 0 RCS short burn test will be evaluated
		= 1 SPS short burn test will be evaluated
		= 2 APS short burn test will be evaluated
		= 3 DPS short burn test will be evaluated
GP04 (Alignment)		Indicator which specifies the type of IMU realignment or vehicle reorientation to be performed (fixed point)
		= +1 Align the active vehicle's IMU to the preferred alignment

Input Symbol	Math Symbol		Definition
		= +2	Align the active vehicle's IMU to exact alignment
		= +3	Align IMU 1 to orientation of IMU 2
		= -3	Align IMU 2 to orientation of IMU 1
		= +4	Align IMU 1 to input REFSMMAT
		= -4	Align IMU 2 to input REFSMMAT
		= +5	Orient vehicle 1 to obtain zero platform gimbal angles
		= -5	Orient vehicle 2 to obtain zero platform gimbal angles
		= +7	Align IMU 1 to nominal CSM alignment
		= -7	Align IMU 2 to nominal CSM alignment
		= +8	Align IMU 1 to nominal LM alignment
		= -8	Align IMU 2 to nominal LM alignment
		= +9	Reorient vehicle 1 relative to present orientation of IMU 1 based upon values of the input GP13, platform inner, middle, and outer gimbal angles
		= -9	Reorient vehicle 2 relative to present orientation of IMU 2 based upon values of the input GP13, platform inner, middle, and outer gimbal angles
		= +10	Realign IMU 1 relative to present orientation of vehicle 1 so that the input values of inner, middle, and outer gimbal angles (GP13) are attained
		= -10	Realign IMU2 relative to the present orientation of vehicle 2 so that the

Input Symbol	Math Symbol	Definition

input values of the inner, middle and outer gimbal angles, (GP13), are attained.

Notes: 1) GP04 must be accompanied by IPTYPE = 3.

2) GP04 = +1 or +2 must be accompanied by GP03 and GP02.

3) GP04 = ±3, ±4, ±7, or ±8 must be input in conjunction with input value GP02 = 0 or 1.

4) GP04 = +4 or -4 must be input in conjunction with GP02 = 0 or 1, GP16, and GP19.

If an external ΔV thrusting maneuver is to be performed with the vehicle attitude oriented in the preferred manner (initial thrust along $\underline{v}_e$) and the IMU aligned in an arbitrary manner (REFSMMAT), then the following procedure must be followed. The external ΔV precompute is followed by the preferred IMU alignment and vehicle attitude orientation to zero gimbal angles. Then, in a following phase, the IMU is aligned again to REFSMMAT.

This procedure is not limited to external ΔV alignments and may be used in general.

5) GP04 = +5 or -5 should be accompanied by input value GP02 = 1.

6) GP04 = +9, -9, +10, or -10 must be accompanied by the input values of the desired platform gimbal angles, GP13. These options (±9 and ±10) do not require the GP02 input and, in fact, GP02 is ignored internally.

Input Symbol	Math Symbol	Definition
GP05		Number of jets to be used during ullage (fixed point) Note: GP05 is input in conjunction with GP08.
GP06		Incremental time between TPI and midcourse ignition (hr)
GP07	I_{sp}	Estimated specific impulse at main ignition, used in the powered-flight steering equations, short burn logic, and computation of t_{GO} (sec)
GP08		Estimated ullage maneuver time, used in computation of ΔV_{ullage} within the Short Burn Logic (sec) Note: Input in conjunction with GP05, number of jets used for ullage. (Refer to definition of GP05 for a more detailed description of the function of GP05 and GP08.)
GP09	m	Estimated vehicle weight at main engine ignition, used in precompute logic to determine thrust acceleration at ignition (lb) This may be input in the precompute phase, along with GC017. If, however, this input is not included within the precompute phase, then the estimated thrust acceleration at ignition will be computed based upon the value of GC017 and actual vehicle mass as it exists at time of precompute
GP10 (Targeting)	ωt	Desired central angle between TPI ignition and TPF ignition (deg)
GP10 (Guidance)	$\Delta t_{tailoff}$	$\Delta t_{tailoff}$ = time to burn compensation for thrust decay (sec) This input can be employed within a main engine thrusting phase which is to be followed by a phase containing the engine thrust decay profile. GP10 (a negative

Input Symbol	Math Symbol	Definition
		quantity) decrements the computed time-to-go in guidance to allow tailoff time for decay phase.

The value of $\Delta t_{tailoff}$ would usually be based upon the following computation:

$$\Delta t_{tailoff} = - \frac{\text{Estimated thrust impulse due to thrust decay (tailoff)}}{\text{Estimated thrust level just prior to thrust decay}}$$

GP11 — Incremental time step (hr)

Used in the internal computation of TTF as outlined in the definition of TTF.

For DØI targeting, GP11 is the ullage time in hours before main engine ignition (if ullage is being simulated).

In addition, GP11 is employed in the internal computation of TMAX which terminates the midcourse precompute phase. This is required only for this precompute phase since it is desirable to end the phase on some incremental time prior to midcourse ignition. However, both the times of midcourse precompute and ignition are specified by input as incremental times relative to the actual time of TPI ignition which is not necessarily known a priori. Hence, TMAX is not input but calculated in the midcourse precompute phase as

$$TMAX = t_{TPI} + GP06 - GP11$$

where, in this case

t_{TPI} = actual time of TPI ignition

GP06 = incremental time between midcourse ignition and t_{TPI}

GP11 = incremental time at which midcourse precompute phase will terminate prior to midcourse ignition

Input Symbol	Math Symbol	Definition
GP12	N	Specifies the apsidal crossing after the CSI maneuver to perform the CDH maneuver = 1. CDH will occur at first apsidal crossing = 2. CDH will occur at second apsidal crossing, etc. This must be input in the CSI precompute phase.
GP13 (Guidance)	$\underline{\Delta V}$	Components of $\underline{\Delta V}$ as input to external ΔV guidance (ft/sec) Note: Coordinate system and meaning of ΔV is determined by GC002.
GP13 (Alignment)	IGA, MGA, OGA	Desired platform gimbal angles (inner, middle, and outer, respectively) upon which a vehicle reorientation or IMU realignment shall be performed (deg) Note: GP13 must be input in conjunction with IPTYPE = 3, and GP04 = +9, -9, +10, or -10. (Refer to these definitions.)
GP16	$\left.\begin{array}{l}\overline{Y}_{IMU} \cdot \overline{X}_{ECI}, \\ \overline{Y}_{IMU} \cdot \overline{Y}_{ECI}, \\ \overline{Y}_{IMU} \cdot \overline{Z}_{ECI}\end{array}\right\}$	Direction cosines of $\overline{Y}_{IMU}$ relative to the ECI coordinate system (Refer to note accompanying definition of input GP19.)
GP19	$\left.\begin{array}{l}\overline{Z}_{IMU} \cdot \overline{X}_{ECI}, \\ \overline{Z}_{IMU} \cdot \overline{Y}_{ECI}, \\ \overline{Z}_{IMU} \cdot \overline{Z}_{ECI}\end{array}\right\}$	Direction cosines of $\overline{Z}_{IMU}$ relative to the ECI coordinate system Notes: 1) GP16 and GP19 must be accompanied by inputs IPTYPE = 3, GP02 = 0 or 1, GP04 = +4 or -4. 2) The values of GP16 and GP19 are used to establish REFSMMAT which is the ECI to the stable member transformation matrix. This matrix is also known as $[\text{IMU I}]^T$

Input Symbol	Math Symbol	Definition
		The REFSMMAT is constructed as follows:

$$[\text{REFSMMAT}] = \begin{bmatrix} \overline{X}_{IMU} \cdot \overline{X}_{ECI} & \overline{X}_{IMU} \cdot \overline{Y}_{ECI} & \overline{X}_{IMU} \cdot \overline{Z}_{ECI} \\ \overline{Y}_{IMU} \cdot \overline{X}_{ECI} & \overline{Y}_{IMU} \cdot \overline{Y}_{ECI} & \overline{Y}_{IMU} \cdot \overline{Z}_{ECI} \\ \overline{Z}_{IMU} \cdot \overline{X}_{ECI} & \overline{Z}_{IMU} \cdot \overline{Y}_{ECI} & \overline{Z}_{IMU} \cdot \overline{Z}_{ECI} \end{bmatrix}$$

where, for example:

$$GP16 = \overline{Y}_{IMU} \cdot \overline{X}_{ECI}, \overline{Y}_{IMU} \cdot \overline{Y}_{ECI}, \overline{Y}_{IMU} \cdot \overline{Z}_{ECI}$$

INAV

Flag to specify update and integration routine to compute navigated state vector (fixed point)

See Section 3.1.1 for complete definition.

IPTYPE

Reorientation or realignment and targeting indicator (fixed point)

= 2 External ΔV (input) targeting (used in the precompute phase prior to an external ΔV maneuver such as the separation or phasing burn, where $\underline{\Delta V}_s$ or $\underline{V}_g$ is specified by the user)

= 3 Attitude reorientation or IMU realignment. Must be accompanied by some or all of the following inputs:

GP02, GP03, GP04, TRIM2, TRIM3

(Refer to these definitions.)

= 8 DØI targeting

= 13 CSI targeting

= 14 CDH targeting

= 15 TPI targeting

= 16 midcourse targeting

= 17 Lambert Aim Point Guidance

Input Symbol	Math Symbol	Definition
ITYPE		Guidance indicator (fixed point) = 0 Coast, no guidance = 11 Thrust, no guidance (used for ullage, thrust decay, etc.) = 13 Powered-flight steering
LATLS		Latitude of landing site (deg)
LONLS		Longitude of landing site (deg)
RN1(RN2)	$\underline{R}_A, \underline{R}_P$	Initial navigation position vector components of vehicle 1 (vehicle 2) (ft) See definition of INAV, Section 2.1.1.
TBNC		Estimated mission time of the lunar landing (hr)
TRIM2	δ_p	Pitch trim angle, defined in the positive sense with a counterclockwise rotation about the body +Y-axis (deg)
TRIM3	δ_y	Yaw trim angle, defined in the positive sense with a counterclockwise rotation about the body +Z-axis (deg) Note: The above trim angle inputs, TRIM2 and TRIM3, may be used in conjunction with inputs IPTYPE = 3, GP03 and GP04 in performing either the preferred or exact IMU realignment. TRIM2 and TRIM3 may also be used to simulate a 3-D initial thrust misalignment. See definition of INAV, Section 3.1.1.
TTF		Phase termination time lapse measured from a reference time (hr). If, in a later phase (from one in which TTF = -1.0 is input) TTF is again input along with TSTOP = 31, the latter phase will be terminated TTF (hours) from the initiation of the phase in which TTF = -1.0 was input.

Input Symbol	Math Symbol	Definition

Note: In any given phase the earliest termination parameter (TMAX, TTR, TTF, or internally computed cutoff time) will end the phase.

There are exceptions to the use of TTF as described above. These exceptions apply to the internal computation of TTF (hr). Prior to the thrusting maneuver, it may be desirable to terminate a phase on some incremental time before ignition. For example, in the case of CDH and TPI, these ignition times are not necessarily known a priori but are obtained from precompute targeting. If the CDH precompute is to occur GP11 (hr) before CDH ignition (determined in the CSI precompute), the GP11 and TTF = -1. must be input in the CSI precompute phase and TSTOP = 31 must appear in the phase immediately preceding the CDH precompute phase. The inputs GP11 and TTF = -1. may also be used in the TPI precompute phase so that if TSTOP = 31 is input in the reorientation phase prior to TPI ignition, then this phase would terminate GP11 (hr) prior to ignition. The computation of TTF related to the aforementioned example is

$$TTF = t_{ignition} - t_{precompute} - GP11$$

The time of terminal phase finalization (TPF) is not known a priori but is obtained by specifying GP10, the desired central angle between TPI and TPF, and computing the corresponding transfer time via the Time-Theta Routine. In order to terminate the coast to rendezvous phase at the computed time of TPF, the input TTF = -1. must appear in the TPI burn phase, and TSTOP = 31 is input in the coast to rendezvous phase. The related computation of TTF is simply

$$TTF = t_{TPF} - t_{TPI}$$

Input Symbol	Math Symbol	Definition
VN1(VN2)	$\underline{V}_A, \underline{V}_P$	Initial navigation velocity vector components of vehicle 1 (vehicle 2) (ft/sec) See definition of INAV, Section 3.1.1.

3.2.2 Abort Guidance System (AGS)*

GC002	DLT2	LM configuration flag (fixed point) = 1 Descent section attached = 0 Descent section not attached
GC006	S10	Guidance selector (fixed point) = 0 Orbit insertion (ascent) guidance = 1 CSI mode = 2 CDH mode = 3 TPI mode (search) = 4 TPI mode (execute) = 5 External delta V guidance
GC009	INCSM	Input CSM state vector selector (fixed point) = 0 User inputs CSM state vector (GC056 and GC059) and epoch time (GC055) = 1 CSM state taken from common at the the phasing point and epoch time (GC055) is set to AGS present time (PT)
GC010	S07	ΔV vector flag (fixed point) = 0 External ΔV vector set up as $\Delta\overline{V} = -J283\overline{U}_1 + J281\overline{V}_1 - J282\overline{W}_1$,

*Table 3-1, Mission Dependent Constants, follows the list of AGS input.

Input Symbol	Math Symbol	Definition
		where $\overline{U}_1$ = unit vector along present LM radius direction, $\overline{V}_1$ = unit vector directed downrange from the LM and parallel to the CSM orbit plant, and $\overline{W}_1$ = unit vector given by $\overline{U}_1 \times \overline{V}_1$; i.e., normal to the CSM plant (sensed velocity increments set to zero). Inputs for J281, J282, and J283 must accompany an input of GC010 = 0
		= 1 External ΔV vector fixed in the reference body centered inertial coordinate system (sensed velocity increments allowed to accumulate). An input of the ΔV vector in reference body centered coordinates must accompany an input of GC010 = 1
GC011	PRTH	Convergence criteria flag for CSI, CDH, and TPI precompute (preset to 0; fixed point)
		= 0 Convergence criteria not cycled
		= 1 Convergence criteria cycled
		Note: GC011 must be an input in the non-thrusting precompute phase. It will be reset internally to 0 upon convergence. GC011 cannot be equal to 1 in a burn phase.
GC012	NPCSI	Number of 2-second cycles allowed for CSI precompute convergence (fixed point, preset to 0)
GC013	DLT11	CSI initiation flag (fixed point)
		= 1 Initiate CSI computations
		= 0 Do not initiate CSI computations
GC014	CVSW	CSI precompute option (fixed point)
		= 0 CSI precompute convergence reached when D6 is less than GC085

Input Symbol	Math Symbol	Definition
		= 1 CSI precompute convergence reached when COP is less than GC085
GC016	K135	Navigation sensed velocity threshold (ft/sec)
GC018	K23	Value for the periapsis radius set to the present LM orbit if the value for the eccentricity (squared) overflows (ft). If $e^2 \geq 2^{-6}$, $e^2 = 0.015625$
GC019	K42	Coefficient of velocity to be gained (VGMAG) magnitude in the computation of time to go before guidance cutoff (GTGO) (sec/ft)
GC023	K43	Coefficient of $(VGMAG)^2$ in the computation of GTGO(sec^2/ft^2)
GC024	K434	Lower limit on AT (the AGS computed thrust acceleration) (ft/sec^2)
GC025	K435	Ullage threshold (ft/sec^2)
GC028	K514	Upper limit on the desired radial jerk ($\dddot{r}_d$) (ft/sec^3)
GC029	K516	Upper limit on the desired out-of-plane jerk ($\dddot{y}_d$) (ft/sec^3)
GC030	K517	Lower limit on the desired out-of-plane jerk ($\dddot{y}_d$) (ft/sec^3)
GC031	K518	Lower limit on the desired radial jerk ($\dddot{r}_d$) when the AGS computed thrust acceleration is greater than 5. ft/sec^2 (ft/sec^3)
GC032	K519	Lower limit on the desired radial jerk ($\dddot{r}_d$) when the AGS computed thrust acceleration is less than 5. ft/sec^2 (ft/sec^3)
GC034	K526	Velocity-to-be-gained threshold (ft/sec)

Input Symbol	Math Symbol	Definition
GC035	J5	Nominal landing site radius magnitude (ft)
GC036	J16	Orbit insertion targeted insertion altitude (ft)
GC037	J21	Vertical pitch steering altitude threshold (i.e., altitude at which the program is to discontinue checking the altitude rate and go directly to steering calculations) (ft)
GC038	J22	Vertical pitch steering altitude rate threshold (i.e., when vehicle attains this input radial rate, the guidance stops limiting the pitch steering to vertical rise and constant velocity to be gained.) (ft/sec)
GC039	J281	Horizontal velocity to be gained (ft/sec)*
GC040	J282	Out-of-CSM plane velocity to be gained (ft/sec)*
GC041	J283	Radial velocity to be gained (ft/sec)*
GC042	TALTUP	AGS time to perform LM altitude update (references to AGS zero reference time, GC075) (sec)
GC043	I_{mp}	Total impulse for first 4 seconds of burn (lb/sec)
GC045	J7	Constant reflecting a curve fit of the semimajor axis (α_L) as a function of the LM-CSM phase angle θ_f (ft) $$\alpha_L = J7 + K410 \cdot \theta_f$$
GC046	J8	Lower limit on the semimajor axis (α_L) (ft)
GC047	J9	Upper limit on the semimajor axis (α_L) (ft)

*Inputs of GC039, GC040, and GC041 must be accompanied by an input of GC010 = 0.

Input Symbol	Math Symbol	Definition
GC048	K410	Constant reflecting a curve fit of the semimajor axis (α_L) as a function of the LM-CSM phase angle θ_f (ft/rad) $\alpha_L = J7 + K410 \cdot \theta_f$
GC049	K412	Lower limit on thrust acceleration at which the constant K519 will be used to limit the desired radial jerk if the LM is staged (ft/sec^2)
GC050	J25	Desired value to be used for an altitude update (ft)
GC055	TE	The CSM state vector epoch time measured from AGS reference time (GC075) (sec) If GC009 = 0, GC055 is a user input. If GC009 = 1, GC055 is computed internally.
GC056	REX REY REZ	CSM state vector corresponding to the epoch time, GC055 (ft) (input when GC009 = 0)
GC059	VEX VEY VEZ	(ft/sec)
GC065 GC066 GC067 (Ext. ΔV)	DVX DVY DVZ	Components of the velocity-to-be-gained vector along coordinate X-, Y-, Z-axes, respectively (ft/sec) (GC010 = 1 must be input)
GC074	RF	Predicted LM radius magnitude at orbit insertion (ft)
GC075	TRAGS	AGS zero reference time measured from launch reference time (hr)
GC077	PVPY	Out-of-plane velocity indicator (preset to 0.0) = 1.0 In CSI or CDH, precompute phase will cause all of the out-of-CSM orbit plane velocity to be removed during CSI or CDH burn. If input as 0.5, half of the velocity will be removed, etc.

Input Symbol	Math Symbol	Definition
GC080	TIGC	Time of TPI ignition referenced to AGS reference time (sec)
GC084	R5DLM	The lower limit for the radial rate at the time of CSI (ft/sec). If the radial rate at the time of CSI is less than GC084, the program assumes the line of apsides of the LM orbit coincides with the CSI time of ignition. Otherwise, the time to perigee is calculated (pre-set to 10. ft/sec).
GC085	CVFACT	Convergence value for the convergence parameter in the CSI precompute (ft/sec or radians). The CSI precompute can converge on either D6 or COP (defined in the AGS CSI print block definitions) as selected by GC014. When D6 is the convergence parameter, the CSI precompute converges when D6 becomes less than or equal to GC085 (ft/sec). When COP is the convergence parameter, the CSI precompute converges when COP becomes less than or equal to GC085 (rad).
GC134 (Targeting)	TD	Time from precompute to the time of ignition used as initial guess for time of TPI ignition (TIGC) (sec)
GP02	TPICV	Type of convergence for TPI (fixed point) = 1 TPI precompute will converge on minimum velocity to be gained = 0 TPI precompute will converge on desired line-of-sight angle
GP03	S16	CDH apsidal crossing selector (fixed point) = 0 Perform CDH burn at first crossing of line of apsides = 1 Perform CDH burn at second crossing of line of apsides = 2 Perform CDH burn at third crossing of line of apsides

Input Symbol	Math Symbol	Definition
GP06 (CSI)	J1	Desired time of TPI measured from AGS reference time (sec)
GP06 (TPI)	J3	Rendezvous offset time for TPI (sec)
GP07 (CSI)	J2	Tangent of desired line-of-sight angle at TPI ignition used in CSI precompute (rad)
GP07 (TPI)	J4	Time from first node of active and passive vehicles to rendezvous used in TPI precompute (sec)
GP08 (CSI)	K228	Coefficient in cost function computation for CSI precompute (ft/sec)
GP08 (TPI)	J6	Desired LM transfer time for direct intercept transfer TPI routine (sec)
GP08 (Ascent)	J23	Orbit insertion radial rate for LM ascent guidance (ft/sec)
GP09 (CSI)	K230	Factor used to increase D6 (D6 defined in AGS CSI printout definitions) in CSI precompute
GP09 (TPI)	K211	Value to set VTMAG to if VFX, VFY, VFZ, or VGX, VGY, VGZ overflows in TPI precompute (ft/sec)
GP10 (CSI)	K25	Initial value and limit on D6 for CSI burn (ft/sec)
GP10 (TPI)	K214	Initial semiparameter perturbation for TPI burn (ft)
GP11 (CSI)	K232	Factor used to decrease D6 for CSI burn
GP11 (TPI)	K217	Loop limit for solution passes of the semiparameter iterator for the TPI precompute
GP12 (CSI)	K233	Lower limit on D6 for the CSI precompute (ft/sec)

Input Symbol	Math Symbol	Definition
GP12 (TPI)	K218	Partial derivative, ∂T, protector for TPI precompute (sec)
GP13 (CSI)	TIGA	Time of CSI ignition measured from AGS reference time (sec)
GP13 (TPI)	K219	Delta semiparameter limiter for TPI precompute (ft)
GP13 (Ascent)	K44	Coefficient in linear expression for predicted final radial rate ($\dot{r}_f$) as a function of the desired insertion radius (r_f) for LM ascent guidance (1/sec)
GP14 (TPI)	K220	Semiparameter iterator convergence check for TPI precompute (sec)
GP14 (Ascent)	K45	Constant in linear expression for $\dot{r}_f$ as a function of r_f for ascent guidance (ft)
GP15 (TPI)	K34	Sine of central angle (C2) limit in TPI for TPI precompute
GP15 (Ascent)	K46	Upper limit on the predicted final radial rate ($\dot{r}_f$) for LM ascent guidance (ft/sec)
GP16 (Ascent)	K49	Factor in computation of the required horizontal velocity at orbit insertion for LM ascent guidance (1/sec)
GP17 (TPI)	J2	Tangent of desired line-of-sight angle for TPI precompute (rad)
INAV		Flag to specify update and integration routine to compute the navigated state vector (fixed point). See Section 3.1.1 for complete definition.
ITYPE		Guidance indicator (fixed point) = 20 AGS guidance mode
JNAV	JNAV	AGS navigation selector (fixed point) = 0 AGS navigation state is continually equal to the actual state

Input Symbol	Math Symbol	Definition
		= +1 Initiate AGS navigation state to the PGNS navigation state and integrate using AGS average-g for a thrusting phase
		= -1 Input AGS navigation state or continue with existing AGS navigation state and integrate using AGS average-g for a thrusting phase
		= +2 Initiate AGS navigation state to PGNS navigation state and integrate using AGS average-g for a coasting phase
		= -2 Input AGS navigation state or continue with existing AGS navigation state and integrate using AGS average-g for a coasting phase
		= +10 Initiate AGS navigation to the actual state and integrate using AGS average-g for a thrusting phase
		= +20 Initiate AGS navigation to the actual state and integrate using AGS average-g for a coasting phase
K21	K21	Universal gravitational constant of the reference body (ft^3/sec^2)
NTHRUS		No-thrust guidance indicator (preset to 0)
		= 0. No guidance during coast
		= 1. Allows guidance to be used in coast phase
RNA	$\bar{r}$	Initial AGS navigation position vector components (ft) (must be accompanied by JNAV = -1 or -2)
VNA	$\bar{v}$	Initial AGS navigation velocity vector components (ft/sec) (must be accompanied by JNAV = -1 or -2)

Table 3-1. Mission Dependent Constants for AGS

Input Symbol	Math Symbol	Input Units	Value: Lunar Mission	Value: Earth Mission
K21	K21	ft^3/sec^2	1.73189E14	1.40858E16
GC018	K23	ft	1.048576E6	4.194304E6
GC019	K42	sec/ft	-4.99286E-5	-4.9969E-5
GC023	K43	sec^2/ft^2	1.2464325E-9	1.6646E-9
GC035	J5	ft	5.7024E6	2.0925738E7
GC036	J16	ft	6.E4	*
GC037	J21	ft	2.5E4	*
GC038	J22	ft/sec	50.	*
GC045	J7	ft	6.055616E6	*
GC046	J8	ft	5.182336E6	*
GC047	J9	ft	7.031232E6	*
GC048	K410	ft/rad	-6.51360E5	*
GC049	K412	ft/sec^2	5.	*
GC074	RF	ft	5.742395E6	16.E6
GP09	J24	ft/sec	5510.	*
GP13	K44	1/sec	0.004	0.001
GP14	K45	ft	5.742395E6	16.E6
GP15	K46	ft/sec	80.	4000.
GP16	K49	1/sec	6.98E-4	*

*Values not defined for earth mission.

3.2.3 LM Powered Landing Guidance and Radar*

Input Symbol	Math Symbol	Definitions
ALTLS		Elevation of landing site as known by guidance (ISCALE units)
ATYPE(3)		LM IMU alignment option (fixed point)
		= 6 Align IMU for LM final descent
DTLAND		Estimated landing time relative to TSTART (hr)
GC001	f_{ph}	= 0 Initial phase at braking (preset to 0) (fixed point)
GC002	f_{DLY}	Landing radar velocity update delay option (fixed point)
		= 0 No time delay is simulated in using the LM navigated state using landing radar velocity information
		= 1 1.6 second delay is simulated in using the LM navigated state from the landing radar velocity update
GC003		Landing radar flag (fixed point)
		= 0 No landing radar
		= 1 Execute landing radar
GC013		Landing radar altitude error options (fixed point)
		= 0 No landing radar altitude noise or bias
		= 1 Landing radar altitude noise and bias table input
		= -1 Landing radar altitude noise and bias set internally

*Table 3-2, LM Powered Landing Guidance Presettings, follows the list of definitions.

Input Symbol	Math Symbol	Definition
GC014		Landing radar velocity error option (fixed point) = 0 No landing radar velocity noise or bias = 1 Landing radar velocity noise and bias table input = -1 Landing radar velocity noise and bias set internally
GC015		Signal-to-noise model option (fixed point) = 0 No signal-to-noise model for landing radar = 1 Turns on landing radar signal-to-noise model
GC016	t_{IG}	Estimated coast duration to DPS ignition (sec)
GC017	T_t	Duration of trim phase (sec) (preset to 26.0)
GC018	T_{ue}	Duration of ullage phase (sec) (preset to 7.5)
GC019 GC021	α_1 β_1	Pair of ordered rotation angles about the body X-axis and antenna Y-axis, respectively, to obtain landing radar antenna axes (deg) (preset to -6.0 and -24.0, respectively)
GC020 GC022	α_2 β_2	Pair of ordered rotation angles about the body X-axis and antenna Y-axis, respectively, to obtain landing radar antenna axes (deg) (preset to -6.0 and 0.0, respectively)
GC023	ξ	Angle between range beam 4 and negative X-axis of landing radar antenna coordinate system (deg) (preset to 20.38)
GC024	h_R	Value of estimated vehicle altitude, below which LR altitude updates should be attempted (ft) (preset to 25000.)
GC025	h_m	Maximum value of navigation altitude for which a LR altitude update is possible (ft) (preset to 35000.0)

Input Symbol	Math Symbol	Definition
GC026	k_h	Scale factor used in updating altitude via the LR (preset to 0.55)
GC027 GC028 GC029	k_{vx} k_{vy} k_{vz}	Scale factors used in updating antenna X-axis, Y-axis, and Z-axis components of velocity via the LR, respectively (preset to 0.40, 0.70, 0.70, respectively)
GC030	h_v	Value of navigation altitude below which LR velocity updates should be attempted (ft))preset to 60000.0)
GC031	V_m	Maximum value of LM speed for which a LR velocity update is possible (ft/sec) (preset to 2000.0)
GC032	$\underline{R}_{FG}$	Desired value of position in the GCS ($\underline{R}_G$) in the braking phase (ft) (preset to 77.133, 0.0, -1.333, respectively)
GC035	$\underline{V}_{FG}$	Desired value of velocity in the CGS ($\underline{V}_G$) in the braking phase (ft/sec) (preset to -3.1, 0.0, 1.3, respectively)
GC038	$\underline{A}_{FG}$	Desired value of acceleration for braking phase xpressed in GCS (ft/sec^2) (preset to 0.15, 0.0, -0.65, respectively)
GC041	j_{ZFG}	Desired value of jerk (time derivative of acceleration) for braking phase, expressed in GCS (Z-component) (ft/sec^3) (preset to 0.034336)
GC042	T_F	Estimated duration of braking phase (sec) (preset to 651.64)
GC043	T_g	Time constant of final descent phase during which velocity will be reduced to the final desired value (sec) (preset to 6.0)
GC044		Mission time at which the landing site redesignation is to occur (sec) (preset to 1.0E21)
GC045	T_{F1}	Estimated duration of visibility phase (sec) (preset to 160.0)

Input Symbol	Math Symbol	Definition
GC046	h_{180}	Altitude at which a 180 degree yaw is executed (ft) (preset to 35000.0)
GC047	q_{min}	Criterion for determining window pointing direction (preset to 0.25882)
GC048	q_{max}	Criterion for determining window pointing direction (preset to 0.42262)
GC049	$\underline{V}_{2G}$	Desired value of $\underline{V}_G$ duration final descent phase (ft/sec) (preset to -3.0, 0.0, 0.0, respectively)
GC052	t_{AP2}	Time criterion at which T_{GO} is sufficiently small to permit an examination of the gimbal angle criterion for LR slewing (sec) (preset to 250.0)
GC054	K_{AP2}	Landing radar slew criterion for the first element of the body to platform transformation matrix (preset to 0.70712).
GC057	$\underline{R}_{FG1}$	Desired value of $\underline{R}_G$ for visibility phase (ft) (preset to 77.133, 0.0, -1.733, respectively)
GC060	$\underline{V}_{FG1}$	Desired value of $\underline{V}_G$ for visibility phase (ft/sec) (preset to -3.1, 0.0, 1.3, respectively)
GC063	$\underline{A}_{FG1}$	Desired value of acceleration for visibility phase expressed in GCS (ft/sec^2) (preset to 0.05, 0.0, -0.65, respectively)
GC066	j_{ZGI}	Desired value of jerk (time derivative of acceleration) for visibility phase expressed in GCS (Z-component) (ft/sec^3) (preset to 0.045636)
GC067	k_V	Speed error scale factor used in ignition time test quantity (sec) (preset to 411.41232)
GC068	V_{IGG}	Nominal speed of LM at DPS ignition relative to rotating moon (ft/sec) (preset to 5574.22)

Input Symbol	Math Symbol	Definition
GC069	k_{ig}	Damping factor used in ignition time iteration (preset to -1.0)
GC070	k_x	Landing site vertical error scale factor used in ignition time test quantity (preset to 0.617631)
GC071	k_y	Cross-range error scale factor used in ignition time test quantity (ft^{-1}) (preset to 0.7551944E-6)
GC072 GC073	R_{IGXG} R_{IGZG}	Nominal position of LM at DPS ignition expressed in guidance coordinate system (GCS) (Y-component is zero) (ft) (preset to -130566.5 and -1413159.7, respectively)
GC074	N_a	Number of pulses for crossrange redesignation
GC075	N_e	Number of pulses for downrange redesignation
GC076 GC077	k_a k_e	Scale factors used in updating the landing site via the landing point designator (LPD) (deg/pulse) (preset to 2.0, 0.5, respectively)
GC081	t_{DUR}	Estimate of burn duration from ignition to touchdown (sec) (preset 651.64)
GC082	t_{ph0}	Time-to-go criteria for switching from braking phase (sec) (preset to 163.0)
GC083	t_{ph1}	Time-to-go criteria for switching from visibility phase to final descent phase (sec) (preset to 0.0)
GC084	S_{MAX}	Maximum available thrust of the descent engine as known by guidance (lb) (preset to 9722.0)
GC086	THMXØ	Maximum thrust capability of actual descent engine at ignition of FTP region (lb) (preset to 9722.0) See note following Table 3-2.
GC087	Δt_{DPSL}	Time duration for descent engine to respond to a desired change in thrust level; nominally set to zero (sec) (preset to 0.0)

Input Symbol	Math Symbol	Definition
GC088	Δt_{TCD}	Computation time from initial PIPA reading to point at which guidance issues a new thrust command; nominally set to zero (sec) (preset to 0.0)
GC089	K_{PT}	Constant to be set to 1 or 0 according to whether guidance is to compensate for the finite time duration of the thrust pulse-train or not, respectively (preset to 0.0)
GC101		ALPHA1, ALPHA2 antenna plate angle about X-axis (deg)
GC103		BETA1, BETA2 antenna plate angle about Y-axis (deg)
GC105		Design angles (Ω_i, i = 1,4) between landing radar beams (deg)
GC109		Misalignment of Ω_i, i = 1,4 (deg)
GC113		Design angles (ξ_i, i = 1,4) between landing radar beams (deg)
GC117		Misalignment of ξ_i, i = 1,4 (deg)
GC121		Distance between c.g. of landing radar plate and c.g. of LM (ft)
GP02	KUNIT	Flag to select output units for powered landing guidance print blocks (fixed point) (preset to 0) = 0 ft, ft/sec, lb (English system) = 1 m, m/sec, kg (metric system)
GP06	TRCRIT	Thrust level during trim phase (lb) (preset to 1050.)
GP08	LØCRIT	Thrust value at which throttle down occurs (lb) (preset to 5888.)
GP09	HICRIT	Upper bound of the throttleable region (lb) (preset to 6616.)
GP10	HRØD	Altitude at which rate of descent (ROD) is initiated (ft) (preset to 0.)

Input Symbol	Math Symbol	Definition
GP11	KROD	Incremental change to vehicle rate of descent ($\dot{h}_o$) at initiation of ROD guidance (ft/sec) (preset to 0.)
GP12 GP13 GP14	CDUD	The desired X-, Y-, Z-platform gimbal angles (respectively) in order to produce the desired thrust orientation (rad)
GP16	KERO	Coefficient of increasing thrust due to throat erosion of descent engine (lb/sec) (preset to 0.5676) See note following Table 3-2.
GP18	Z_{AXS}	Z-axis direction selector (preset to 1.0) = 1.0 Z-body axis pointed up (i.e., away from moon) =-1.0 Z-body axis pointed down (i.e., towards moon)
INAV		Flag to specify update and integration routine to compute the navigated state vector (fixed point) See Section 3.1.1 for complete definition.
IPTYPE		= 7 Executes preignition algorithm, aligns LM, and coasts to ullage time (fixed point)
ISTYPE		Preset guidance constant option (fixed point) = 0 Guidance constants must be input = 8 Guidance constants are initialized according to Table 3-2
ITYPE		= 12 Execute descent guidance (fixed point)
LATLS		Latitude of landing site as known by dynamics prior to redesignation (deg)
LMDVEX	V_E	Estimated effective DPS exhaust velocity (ft/sec) (preset to 9668.3016)
LMMASS		Estimated mass of LM (lb)

Input Symbol	Math Symbol	Definition
LONLS		Longitude of landing site as known by guidance and dynamics prior to redesignation (deg)
LRAB	LRAB	LR altitude beam bias table. Input as bias value (ft) versus beam slant range (BMRANG) (ft)
LRAN	LRAN	LR altitude beam noise table. Input as maximum noise value (ft) versus beam slant range (BMRANG) (ft)
LRELV	LRELV	LR terrain table. If used as a simple table, input is surface elevation with respect to the landing site (ft) versus the surface range to the landing site from the point where the LR beam intersects the terrain (BEAMSR) (ft). If used as a master table, input is subtable number versus the selenographic angle defined at the landing site and measured clockwise from selenographic north to the vector from the LR beam/moon intersection point to the landing site (AZMTH) (0. to 360. deg). Subtables are input as defined above in the simple table definition.
LRVB	LRVB	LR velocity beam(s) bias table(s). If used as a simple table, input is bias value (ft/sec) for all three velocity beams versus the doppler beam velocity (DOPVEL) (ft/sec). If used as a master table, input is table number (i.e., 1, 2, and 3) versus the beam number (KBEAM = 1., 2., and 3.). Subtables are input as bias value (ft/sec) versus the doppler beam velocity (DOPVEL) (ft/sec)
LRVN	LRVN	LR velocity beam(s) noise table(s). If used as a simple table, input is maximum noise value (ft/sec) for all three velocity beams versus the doppler beam velocity (DOPVEL) (ft/sec). If used as a master table, input is table number (i.e., 1, 2, and 3) versus the beam number (KBEAM = 1., 2., 3.). Subtables are input as maximum noise values (ft/sec) versus the doppler beam velocity (DOPVEL) (ft/sec)

Input Symbol	Math Symbol	Definition
RALTFT		Phase termination altitude relative to the lunar terrain (ft)
RN1(RN2)	$\underline{R}_A, \underline{R}_P$	Initial navigated position vector of vehicle 1 (vehicle 2) (ft). See definition of INAV, Section 3.1.1.
TBNC		Estimated mission time of the lunar landing (hr). If input, TBNC will override DTLAND.
VN1(VN2)	$\underline{V}_A, \underline{V}_P$	Initial navigated velocity vector of vehicle 1 (vehicle 2) (ft/sec). See definition of INAV, Section 3.1.1.

Table 3-2. LM Powered Landing Guidance Presettings*

Input Symbol	Dimension	Math Symbol	Output Mnemonic	Preset Value	Input Units
GC017	scalar	τ_t	TAUT	26.0	sec
GC018	scalar	$\tau_{U\ell}$	TAUUL	7.5	sec
GC019	scalar	α_1	ALPH1	-6.0	deg
GC020	scalar	α_2	ALPH2	-6.0	deg
GC021	scalar	β_1	BETA1	-24.0	deg
GC022	scalar	β_2	BETA2	0.0	deg
GC023	scalar	ξ	XI	20.38	deg
GC024	scalar	h_R	HR	25,000.0	ft
GC025	scalar	h_m	HM	35,000.0	ft
GC026	scalar	k_h	KH	0.55	none
GC027	scalar	k_{VX}	KVX	0.40	none
GC028	scalar	k_{VY}	KVY	0.70	none
GC029	scalar	k_{VZ}	KVZ	0.70	none
GC030	scalar	h_V	HV	60,000.0	ft
GC031	scalar	V_m	VM	2,000.0	ft/sec
GC032	vector	$\underline{R}_{FG}$	RFG	77.133	ft
				0.0	ft
				-1.333	ft
GC035	vector	$\underline{V}_{FG}$	VFG	-3.1	ft/sec
				0.0	ft/sec
				1.3	ft/sec
GC038	vector	$\underline{A}_{FG}$	AFG	0.15	ft/sec^2
				0.0	ft/sec^2
				-0.65	ft/sec^2
GC041	scalar	j_{ZFG}	JFGZ	0.034336	ft/sec^2
GC042	scalar	τ_F	TAUF	651.64	sec
GC043	scalar	τ_g	TAU2	6.0	sec
GC044	scalar	none	TLPD	1.0E21	sec
GC045	scalar	τ_{F1}	TAUF1	160.0	sec
GC046	scalar	h_{180}	H180	35,000.0	ft

*(Definitions are given by output mnemonic in Section 4.2.1.)

Table 3-2. LM Powered Landing Guidance Presettings (Continued)

Input Symbol	Dimension	Math Symbol	Output Mnemonic	Preset Value	Input Units
GC047	scalar	q_{min}	QMIN	0.25882	none
GC048	scalar	q_{max}	QMAX	0.42262	none
GC049	vector	$\underline{V}_{2G}$	VG2	-3.0	ft/sec
				0.0	ft/sec
				0.0	ft/sec
GC052	scalar	t_{AP2}	TAP2	250.0	sec
GC054	scalar	K_{AP2}	KAP2	.70712	none
LMDVEX	scalar	V_E	VE	9,668.3015	ft/sec
GC057	vector	$\underline{R}_{FG1}$	RFG1	77.133	ft
				0.0	ft
				-1.733	ft
GC060	vector	$\underline{V}_{FG1}$	VFG1	-3.1	ft/sec
				0.0	ft/sec
				1.3	ft/sec
GC063	vector	$\underline{A}_{FG1}$	AFG1	0.05	ft/sec^2
				0.0	ft/sec^2
				-0.65	ft/sec^2
GC066	scalar	j_{ZG1}	JFGZ1	0.045636	ft/sec^3
GC067	scalar	k_V	KV	411.41232	sec
GC068	scalar	V_{IGG}	VIGG	5,574.22	ft/sec
GC069	scalar	k_{ig}	KIG	-1.0	none
GC070	scalar	k_X	KX	.617631	none
GC071	scalar	k_Y	KY	0.7551944E-6	ft^{-1}
GC072	scalar	R_{IGXG}	RIGXG	-130,566.5	ft
GC073	scalar	R_{IGZG}	RIGZG	-1,413,159.7	ft
GC076	scalar	k_a	KA	2.0	deg/pulse
GC077	scalar	k_e	KE	0.5	deg/pulse
GC081	scalar	t_{DUR}	TBDUR	651.64	sec
GC082	scalar	t_{ph0}	TPHO	163.0	sec
GC083	scalar	t_{ph1}	TPH1	0.0	sec

Table 3-2. LM Powered Landing Guidance Presettings (Continued)

Input Symbol	Dimension	Math Symbol	Output Mnemonic	Preset Value	Input Units
GC084	scalar	S_{MAX}	SMAX	9,722.0	lb
GC086	scalar	THMXØ*	THMXO	9,722.0	lb
GC087	scalar	Δt_{DPSL}	DTDPS	0.0	sec
GC088	scalar	Δt_{TCD}	DTCTD	0.0	sec
GC089	scalar	K_{PT}	KPT	0.0	none
GP02	scalar	KUNIT	none	0	none
GP06	scalar	TRCRIT	none	1050.	lb
GP08	scalar	LØCRIT	none	5888.	lb
GP09	scalar	HICRIT	none	6616.	lb
GP10	scalar	HRØD	none	0.0	ft
GP11	scalar	KRØD	none	0.0	ft/sec
GP16	scalar	KERØ*	KERO	.5676	lb/sec
GP18	scalar	Z_{AXS}	none	1.0	none

*These constants are coefficients for the equation THMAXD = THMXO + KERO (TFI - TAUT), where THMAX is the maximum dynamics thrust that the descent engine can produce, TFI is computed internally, and TAUT is the preset constant GC017. The equation is used to simulate the effect of throat erosion in the absence of a DPS model. (See Section 4.2.1)

3.2.4 LM Ascent Guidance

Input Symbol	Math Symbol	Definition
ALSC		True anomaly of intercept position (deg)
ALTA		Altitude of the target above the landing site (ISCALE units)
ALTB		Desired burnout altitude above the landing site (ISCALE units)
ALTLS		Altitude of the landing site referenced to the nominal radius of the reference body (ISCALE units)
DGAM		Desired true anomaly at burnout for IMDC = 3 option or desired flight-path angle at burnout for IMDC = 5 option (deg)
DRT2		Desired velocity vector in the guidance coordinate system (ISCALE units)
DVEL		Desired velocity magnitude at burnout (ISCALE units)
GC020	TTG	Estimated time to go to cutoff (required when GP04 = 1 or 2) (sec)
GC021	DTI	Thrust phase integration step size (required when GP04 = 2) (hr)
GC023	THRM6D	Total RCS thrust (required when ILPTR = 1) (lb)
GD7VE	VE	Exhaust velocity (ft/sec)
GP04	IFLAB	Abort flag (fixed point) (preset to 0) = 0 Nominal ascent from surface = 1 APS abort = 2 DPS abort = 3 Abort stage (used for an APS abort phase following a DPS abort phase)
GP21	TAU	Initial mass flow rate ratio (required when GP04 = 2) (sec)

Input Symbol	Math Symbol	Definition
ILPTR		RCS insertion steering indicator (fixed point) (preset to 0) = 0 APS or DPS orbit insertion = 1 RCS orbit insertion
IMDC		Guidance target indicator (fixed point) = 0 Target is circular orbit speed at the burnout position (circular orbit insertion) = 1 Target is an intercept with a desired position and time of flight (Lambert's solution) = 2 Target is a burnout into a Hohmann transfer orbit having an apoapsis altitude of (ALTA) = 3 Target is computed from the desired true anomaly (DGAM), true anomaly of the intercept position (ALSC), and desired target altitude above the landing site (ALTA) = 4 Target is computed from the desired velocity vector in the guidance coordinate system (DRT2) = 5 Target is computed from the desired flight-path angle (DGAM) and the desired velocity magnitude (DVEL)
INAV		Flag to specify update and integration routine to compute the navigated state vector (fixed point). See Section 3.1.1 for complete defintion.
IPCA		Target plane indicator (fixed point) = 0 Target plane is defined by the position of the active and passive vehicles (NV = 2) = 1 Target plane is defined by the position and velocity of the passive vehicle (NV = 2) = 2 Target plane is defined by the target position (CSM) and velocity (DCSM) (NV = 2)

Input Symbol	Math Symbol	Definition
		= 3 Target plane is defined by the current position of the active vehicle and input target position vector RT
		= 4 Target plane is defined by the input target position (RT) and velocity (DRT) vectors
ITYPE		ARM guidance selector (fixed point)
		= 7 Selects PGNS orbit insertion
RN1(RN2)	$\underline{R}_A, \underline{R}_P$	Initial navigation position vector components of vehicle 1 (vehicle 2) (ft) See definition of INAV, Section 3.1.1.
RRATE		Desired radial rate for vertical rise termination (ISCALE units)
RANGE		Desired injection cross-range distance measured from the target plane (ISCALE units)
RT, DRT		Input target position and velocity vectors, respectively, in the reference body centered inertial coordinate system (ISCALE units)
TBNC		Time to go when burnout position control is abandoned; i.e., B = D = 0 (B and D defined in PGNS ascent guidance printout definitions) (sec)
TGØKT		Time-to-go constant (preset to 0.5)
VN1(VN2)	$\underline{V}_A, \underline{V}_P$	Initial navigation velocity vector components of vehicle 1 (vehicle 2) (ft/sec). See definition of INAV, Section 3.1.1.

4. OUTPUT

The A-215 program is an extension of the Apollo Reference Mission Program (Version ARM07) and employs the same output scheme with the addition of several special guidance print blocks. Therefore, this section will discuss only those print blocks which are not included in the ARM07 User's Manual or which have been changed. For a complete description of print control, output units, and standard ARM07 output, see Reference 1, Section 17.

4.1 CHANGED PRINT GROUP FLAGS (See Reference 1, Section 17.1 for complete list of print group flags)

PRTG18=2. Prints EXTERNAL DELTA-V, CDH, CSI, TPI, MIDCOURSE, and LAMBERT AIMPOINT precomputation blocks

PRTG19=2. and ITYPE=7 Prints PGNS LM ascent output

PRTG19=2. and ITYPE=12 Prints LM descent output

PRTG19=2. and ITYPE=13 Prints cross-product steering output

PRTG19=2. and ITYPE=20 Prints abort guidance system output

PRTG20=2. Prints guidance dynamics output

PRTG21 Prints AGS output in ARM07.
Does not reference any print block in A-215.

PRTG27=2. Prints LM guidance - digital autopilot interface output

PRTG28=2. and NV=2, ITYPE=7,12,13, or 20 prints real-time displays

4.2 NEW PRINT

4.2.1 Output at Beginning of Each Phase

Phase Identification

Input Data Array

Input Thrust Data

Constant Array

Potential Constants

LM Powered Landing Guidance Preset Constants (printed if IPTYPE = 7 or ITYPE = 12)

Format

PRE-IGNITION CONSTANTS

RIGXG	RIGZG	VIGG	KX	KY	KV
KIG	VE	TAUT	TAUUL	TBDUR	FL2PH

LANDING RADAR CONSTANTS

ALPH1	ALPH2	BETA1	BETA2	XI	HM
HR	HV	KH	KVX	KVY	KVZ
VM	TAP2	KAP2			

LANDING SITE REDESIGNATION CONSTANTS

TLPD	KA	KE

BRAKING PHASE

RFG(X)	(Y)	(Z)	VFG(X)	(Y)	(Z)
AFG(X)	(Y)	(Z)	JFGZ	TAUF	TPHO

VISIBILITY PHASE

RFG1(X)	(Y)	(Z)	VFG1(X)	(Y)	(Z)
AFG1(X)	(Y)	(Z)	JFGZ1	TAUF1	TPH1

DESCENT PHASE

VG2(X)	(Y)	(Z)	TAU2

ATTITUDE CONSTANTS

H180	QMAX	QMIN

THROTTLE CONSTANTS

DTDPS	DTCTD	KPT	THMXØ	SMAX	KERØ

<u>Symbol Definitions</u>

RIGXG, RIGZG	Nominal position of LM at DPS ignition expressed in guidance coordinate system (GCS) (Y-component is zero) (ft)
VIGG	Nominal speed of LM at DPS ignition relative to rotating moon (ft/sec)
KX	Landing site vertical error scale factor used in ignition - time test quantity
KY	Crossrange error scale factor used in ignition - time test quantity (ft^{-1})
KV	Speed error scale factor used in ignition - time test quantity (sec)
KIG	Damping factor used in ignition - time iteration
VE	Effective exhaust velocity magnitude of DPS engine (ft/sec)
TAUT	Duration of trim phase (sec)
TAUUL	Duration of ullage phase (sec)
TBDUR	Estimate of burn duration from ignition to touchdown (sec)
FL2PH	Flag set to 1 or 0 according to whether the two-phase guidance or the pseudo-aim point guidance is to be executed, respectively.
ALPH1, BETA1	Pair of ordered rotation angles about the body X-axis and antenna Y-axis, respectively, to obtain landing radar antenna axes (deg)
ALPH2, BETA2	Pair of ordered rotation angles about the body X-axis and antenna Y-axis, respectively, to obtain landing radar antenna axes (deg)
XI	Angle between range beam 4 and negative X-axis of landing radar antenna coordinate system (deg)
HM	Maximum value of navigation altitude for which a LR altitude update is possible (ft)
HR	Value of estimated vehicle altitude, below which LR altitude updates should be attempted (ft)
HV	Value of navigation altitude below which LR velocity updates should be attempted (ft)

KH	Scale factor used in updating altitude via the LR
KVX KVY KVZ	Scale factors used in updating antenna X-, Y-, and Z-axis components of velocity via the LR, respectively
VM	Maximum value of LM speed for which a LR velocity update is possible (ft/sec)
TAP2	Time criterion at which T_{GO} is sufficiently small to permit an examination of the gimbal angle criterion for LR slewing (sec)
KAP2	Landing radar slew criterion for the first element of the body to platform transformation matrix
TLPD	Mission time at which the landing site redesignation is to occur (sec)
KA KE	Scale factors used in updating the landing site via the landing point designator (LPD) (deg/pulse)
RFG	Desired value of position in the GCS ($\underline{R}_G$) in the braking phase (ft)
VFG	Desired value of velocity in the GCS ($\underline{V}_G$) in the braking phase (ft/sec)
AFG	Desired value of acceleration for braking phase expressed in GCS (ft/sec^2)
JFGZ	Desired value of jerk (time derivative of acceleration) for braking phase, expressed in GCS (Z-component) (ft/sec^3)
TAUF	Estimated duration of braking phase (sec)
TPHØ	Time-to-go criteria for switching from braking phase (sec)
RFG1	Desired value of $\underline{R}_G$ for visibility phase (ft)
VFG1	Desired value of $\underline{V}_G$ for visibility phase (ft/sec)
AFG1	Desired value of acceleration for visibility phase expressed in GCS (ft/sec^2)
JFGZ1	Desired value of jerk (time derivative of acceleration) for visibility phase expressed in GCS (Z-component) (ft/sec^3)
TAUF1	Estimated duration of visibility phase (sec)
TPH1	Time-to-go criteria for switching from visibility phase to final descent phase (sec)
VG2	Desired value of $\underline{V}_G$ during final descent phase (ft/sec)
TAU2	Time constant of final descent phase during which velocity will be reduced to the final desired value (sec)
H180	Altitude at which a 180-degree yaw is executed (ft)

QMAX	Criterion for determining window pointing direction
QMIN	Criterion for determining window pointing direction
DTDPS	Time duration for descent engine to respond to a desired change in thrust level; nominally set to zero (sec)
DTCTD	Computation time from initial PIPA reading to point at which guidance issues a new thrust command; nominally set to zero (sec)
KPT	Constant to be set to 1 or 0 according to whether guidance is to compensate for the finite time duration of the thrust pulse-train or not, respectively (sec)
THMXØ	Maximum thrust capability of actual descent engine at initiation of FTP region (lb)
SMAX	Maximum available thrust of the descent engine as known by guidance (lb)
KERØ	Coefficient of increasing thrust due to throat erosion of descent engine (lb/sec)

LM Powered Landing Guidance preignition Block (printed if IPTYPE = 7)

Format

PRE-IGNITION

TUL

RNAVP(X)	(Y)	(Z)	VNAVP(X)	(Y)	(Z)
RLSP(X)	(Y)	(Z)	XBDP(X)	(Y)	(Z)
YBDP(X)	(Y)	(Z)	ZBDP(X)	(Y)	(Z)

Symbol Definition

TUL	Mission time to start of ullage measured from the beginning of run (sec)
RNAVP	LM position at TUL expressed in platform coordinate system (PCS) (ft)
VNAVP	LM velocity at TUL expressed in PCS (ft/sec)
RLSP	Position of landing site at TUL expressed in PCS (ft)
XBDP	Desired orientation of body X-axis expressed in PCS
YBDP	Desired orientation of body Y-axis expressed in PCS
ZBDP	Desired orientation of body Z-axis expressed in PCS

The IMU System and the Vehicle Attitude and IMU Maneuver Angles (printed if TITLE = 1.)

Format

VEHICLE "ID" INERTIAL MEASUREMENT UNIT

XIMUX	YIMUX	ZIMUX
XIMUY	YIMUY	ZIMUY
XIMUZ	YIMUZ	ZIMUZ

VEHICLE "ID" ATTITUDE MANEUVER ANGLES

ALPHA	BETA	GAMMA

VEHICLE "ID" IMU MANEUVER ANGLES

ALPHA	BETA	GAMMA

Symbol Definitions

XIMUX XIMUY XIMUZ	Inertial coordinates of the X-axis (longitudinal axis) of the IMU system
YIMUX YIMUY YIMUZ	Inertial coordinates of the Y-axis of the IMU system
ZIMUX ZIMUY ZIMUZ	Inertial coordinates of the Z-axis of the IMU system
ALPHA BETA GAMMA	Euler maneuver angles of the attitude and IMU orientation at phase initiation (ATYPE options have been executed) with respect to orientation at the end of the previous phase (deg)

4.2.2 Selenocentric Reference (output if vehicle in moon reference and PRTG2 = 2.0, output if vehicle in moon or earth reference and PRTG2 = 3.0)

Format

SELENOCENTRIC

XL	YL	ZL	DXL	DYL	DZL
RL	DECL	RAL	VL	PTHL	AZL

(If vehicle ID = NVEHT, INAV(NVEHT) is not 0, and vehicle is in moon reference)

RNX	RNY	RNZ	VNX	VNY	VNZ
RNPX	RNPY	RNPZ	VNPX	VNPY	VNPZ

(If vehicle ID = NVEHT, JNAV is not 0, and vehicle is in moon reference)

RNAX	RNAY	RNAZ	VNAX	VNAY	VNAZ

Symbol Definitions

XL, YL, ZL, DXL, DYL, DZL	Inertial selenocentric cartesian coordinates (position and velocity in units of OSCALE)
RL, DECL, RAL, VL, PTHL, AZL	Inertial selenocentric polar coordinates (distance and velocity in OSCALE units, angles in degrees)
RL	Radius vector magnitude
DECL	Declination
RAL	Right ascension
VL	Velocity vector magnitude
PTHL	Flight-path angle
AZL	Azimuth
RNX, RNY, RNZ	PGNS navigated position (units of OSCALE)
VNX, VNY, VNZ	PGNS navigated velocity (units of OSCALE)
RNPX, RNPY, RNPZ	PGNS navigated position in ideal IMU coordinate system (units of OSCALE)
VNPX, VNPY, VNPZ	PGNS navigated velocity in ideal IMU coordinate system (units of OSCALE)
RNAX, RNAY, RNAZ	AGS navigated position (units of OSCALE)
VNAX, VNAY, VNAZ	AGS navigated velocity (units of OSCALE)

4.2.3 Selenographic Reference (output if vehicle in moon reference and PRTG3=2.0, output if vehicle in moon or earth reference and PRTG3=3.0)

Format

SELENOGRAPHIC

XS	YS	ZS	DXS	DYS	DZS
ALTS	LATS	LØNS	VRS	PTR	AZR
LTS	LNS	LTE	LNE	DSMP	RSMP
LIN	LAN	LAP	DR	VT	TRALT

Symbol Definitions

XS, YS, ZS, DXS, DYS, DZS - Rotational selenographic Cartesian coordinates (position and velocity in OSCALE units)

ALTS, LATS LØNS, VRS, PTR, AZR - Rotational selenographic Polar coordinates (distance and velocity in OSCALE units, angles in degrees)

ALTS	Altitude above spherical moon
LATS	Latitude
LØNS	Longitude
VRS	Velocity vector magnitude
PTR	Flight-path angle
AZR	Azimuth
LTS	Selenographic latitude of the sun (deg)
LNS	Selenographic longitude of the sun (deg)
LTE	Selenographic latitude of the earth (deg)
LNE	Selenographic longitude of the earth (deg)
DSMP	Declination of the sun with respect to the moon orbit plane coordinate system (deg)
RSMP	Right ascension of the sun with respect to the moon orbit plane coordinate system (deg)
LIN	Selenographic inclination of the flight plane of the vehicle (deg)
LAN	Longitude of the ascending node (deg)
LAP	Selenographic argument of periapsis (deg)

DR	Radial component of velocity (units of OSCALE)
VT	Tangential component of velocity (units of OSCALE)
TRALT	Altitude above the landing site (units of OSCALE)

4.2.4 Geocentric Reference (output if PRTG4=2.0)

Format

GEOCENTRIC

X	Y	Z	DX	DY	DZ
R	DEC	RA	V	PTH	AZ

(If vehicle is in earth reference, vehicle ID = NVEHT, and INAV(NVEHT) is not 0)

RNX	RNY	RNZ	VNX	VNY	VNZ
RNPX	RNPY	RNPZ	VNPX	VNPY	VNPZ

(If vehicle is in earth reference, vehicle ID = NVEHT, and JNAV not 0)

RNAX	RNAY	RNAZ	VNAX	VNAY	VNAZ

Symbol Definitions

X, Y, Z, DX, DY, DZ - Inertial geocentric Cartesian coordinates (position and velocity in units of OSCALE)

R, DEC, RA, V, PTH, AZ - Inertial geocentric Polar coordinates (distance and velocity in units of OSCALE, angles in degrees)

R	Radius vector magnitude
DEC	Declination
RA	Right ascension
V	Velocity vector magnitude
PTH	Flight-path angle
AZ	Aximuth

RNX, RNY, RNZ - PGNS navigated position (units of OSCALE)

VNX, VNY, VNZ - PGNS navigated velocity (units of OSCALE)

RNPX, RNPY, RNPZ - PGNS navigated position in ideal IMU coordinates (units of OSCALE)

VNPX, VNPY, VNPZ - PGNS navigated velocity in ideal IMU coordinates (units of OSCALE)

RNAX, RNAY, RNAZ - AGS navigated position (units of OSCALE)

VNAX, VNAY, VNAZ - AGS navigated velocity (units of OSCALE)

4.2.5 Landing Site Coordinates (output if vehicle is in moon reference and PRTG12=2.0)

Format

LANDING SITE COORDINATES

ALLS	BTLS	ALLSW1	ALLSW2	ALLSS	BTLST
SØLLS					

(The last two items are printed only when the vehicle ID is equal to CSM)

LATLS	LØNLS	RANG	ELV	AZM	DRNL

(If the vehicle is the active vehicle, the following line is printed)

TANG	SRANG	TRALT	ALTST

Symbol Definitions

ALLS	Angle between the line of sight to the landing site and the X-axis of the vehicle (deg)
BTLS	Angle between the projection of the line of sight to the landing site into the Y-Z plane and the negative Z-axis of the vehicle. Angle is measured positively from the negative Z-axis toward the positive Y-axis (deg)
ALLSW1	Angle between the centerline of window number one and the line of sight to the landing site (deg)
ALLSW2	Angle between the centerline of window number two and the line of sight to the landing site (deg)
ALLSS	CSM shaft angle to direct the line of sight to the landing site (deg)
RTLST	CSM trunnion angle to direct the line of sight to the landing site (deg)
SØLLS	Sunlight incidence angle on landing site (elevation of sun measured from geocentric or selenocentric horizontal at the landing site. Negative value indicates sunlight not incident.) (deg)
LATLS	Latitude of the landing site (deg)
LØNLS	Longitude of the landing site (deg)
RANG	Range from vehicle to landing site (units of OSCALE)

ELV	Elevation angle of vehicle measured from a plane tangent to the target body at the landing site (deg)
DRNL	Range rate (units of OSCALE)
TANG	Angle between the X-axis of the thrusting vehicle and the line of sight to the landing site (deg)
SRANG	Surface range (units of OSCALE)
TRALT	Altitude above the landing site (units of OSCALE)
ALTST	Altitude of landing site above the mean radius of the moon (units of OSCALE)

4.2.6 Precomputation Print Blocks (output if vehicle ID = NVEHT and PRTG18=2.0)

4.2.6.1 External Delta-V Precomputation Block (output if IPTYPE=3)

Format

EXTERNAL DELTA V PRECOMPUTATION

TT	TIG	THET	ATP	PTRIM	YTRIM
RXTGN	VXTGN	UXTIG	M11	M12	M13
RYTGN	VYTGN	UYTIG	M21	M22	M23
RZTGN	VZTGN	UZTIG	M31	M32	M33
GXTIG	DVXS	DVXP	DVXC	DVXT	VGX
GYTIG	DVYS	DVYP	DVYC	DVYT	VGY
GZTIG	DVZS	DVZP	DVZC	DVZT	VGZ
UPX	XVX	YVX	ZVX	UTXSM	DVXSE
UPY	XVY	YVY	ZVY	UTYSM	DVYSE
UPZ	XVZ	YVZ	ZVZ	UTZSM	DVZSE
IGANG	MGANG	ØGANG	VVG		

Symbol Definitions

(All in ECI unless noted.)

TT	Evaluation time reference to launch time (sec)
TIG	Time of main ignition referenced to launch time (sec)
THET	Estimated burn angle, θ_T (deg)
ATP	Estimated thrust acceleration at main ignition, a_T' (ft/sec^2)
PTRIM YTRIM	Pitch and yaw trim angles upon which the preferred or exact alignment is based (deg)

RXTGN RYTGN RZTGN	Navigated position vector at TIG from Encke and average-g integration (ft)
VXTGN VYTGN VZTGN	Navigated velocity vector at TIG from Encke and average-g integration (ft/sec)
UXTIG UYTIG UZTIG	Initial desired thrust direction unit vector, $\underline{U}_T$, as determined in the precompute
M_{ij}	M matrix $[M]$, transformation from local horizontal system at TIG to ECI
GXTIG GYTIG GZTIG	Gravity vector at TIG, $\underline{g}(t_{ig})$ (ft/sec^2)
DVXS DVYS DVZS	Impulsive velocity vector components in local horizontal coordinate system, $\underline{\Delta V}_S$ (ft/sec)
DVXP DVYP DVZP	In-plane components of $\underline{\Delta V}_S$ vector in local horizontal coordinate system at TIG, $\underline{\Delta V}_p$ (ft/sec)
DVXC DVYC DVZC	$\underline{\Delta V}_p$ vector corrected for estimated burn arc in local horizontal system at TIG, $\underline{\Delta V}_c$ (ft/sec)
DVXT DVYT DVZT	Total impulsive velocity-to-be-gained vector components in local horizontal coordinate system at TIG, $\underline{\Delta V}_T$ (ft/sec)
VGX VGY VGZ	Velocity-to-be-gained vector, $\underline{v}_g$ (ft/sec)
UPX UPY UPZ	Unit vector coincident with, but opposite to, the angular momentum vector at TIG, $\underline{U}_p$
XVX XVY XVZ	Direction cosines of the preferred vehicle X-axis orientation relative to the ECI system
YVX YVY YVZ	Direction cosines of the preferred vehicle Y-axis orientation relative to the ECI system
ZVX ZVY ZVZ	Direction cosines of the preferred vehicle Z-axis orientation relative to the ECI system
UTXSM UTYSM UTZSM	Unit vector specifying the initial desired thrust direction, as determined in the precompute, in the IMU (stable member) coordinate system

DVXSE DVYSE DVZSE	Impulsive $\underline{\Delta V}_S$ in the ECI coordinate system (ft/sec)
IGANG	Inner (pitch) platform gimbal angle (deg)
MGANG	Middle (yaw) platform gimbal angle (deg)
ØGANG	Outer (roll) platform gimbal angle (deg)
VVG	Initial velocity-to-be-gained magnitude (ft/sec)

4.2.6.2 CSI Precomputation Block (output if IPTYPE=13)

Format

CSI PRECOMPUTATION

TIME	TCSI	TTPI	TCDH	ELV	AN
DVCSI	DVCDH	DELH	HAP1	HAP2	PMIN
DCSIX	DCDHX	RPXN	VPXN	RAXN	VAXN
DCSIY	DCDHY	RPYN	VPYN	RAYN	VAYN
DCSIZ	DCDHZ	RPZN	VPZN	RAZN	VAZN
RA1X	VA1X	RA2X	VA2X	RA3X	VA3X
RA1Y	VA1Y	RA2Y	VA2Y	RA3Y	VA3Y
RA1Z	VA1Z	RA2Z	VA2Z	RA3Z	VA3Z
UH1X	V1STX	UH2X	V2STX	UH3X	RP3X
UH1Y	V1STY	UH2Y	V2STY	UH3Y	RP3Y
HU1Z	V1STZ	UH2Z	V2STZ	UH3Z	RP3Z
ECC	DELV	VPV	VAV	FP1	K
GAM	TD2	AA2	AP2	DT2	DT3

Symbol Definitions

(All in ECI unless noted.)

TIME	Time of precompute (sec)
TCSI	Input time of CSI (sec)
TTPI	Input time of TPI (sec)
TCDH	Computed time of CDH (sec)

ELV	Desired elevation angle at TPI (deg)
AN	Input integral multiplier of half the orbit period used to determine the apsidal point at which CDH is performed (AN = 1.; CDH at first apside, AN = 2.; CDH at second apside crossed, etc.)
DVCSI	Signed magnitude of $\underline{\Delta}V$ at TCSI (always horizontal) (ft/sec)
DVCDH	Magnitude of $\underline{\Delta}V$ required at TCDH (ft/sec)
DELH	Differential altitude between active and passive vehicle orbits at TCDH measured along the extension of the active vehicle's position vector (n mi)
HAP1	Altitude of perigee of active vehicle after applying DVCSI (n mi)
HAP2	Altitude of perigee of active vehicle after applying DVCDH (n mi)
PMIN	Lower limit on allowable altitude of perigee (n mi)
DCSIX, DCSIY, DCSIZ	Components of $\underline{\Delta}V$ at TCSI (ft/sec)
DCDHX, DCDHY, DCDHZ	Components of required $\underline{\Delta}V$ at TCDH in the local horizontal coordinate system (ft/sec)
RPXN, RPYN, RPZN	Components of navigated position vector of passive vehicle at TIME from onboard Encke integration (ft)
VPXN, VPYN, VPZN	Components of navigated velocity vector of passive vehicle at TIME from onboard Encke integration (ft/sec)
RAXN, RAYN, RAZN	Components of navigated position vector of active vehicle at TIME from onboard Encke integration (ft)
VAXN, VAYN, VAZN	Components of navigated velocity vector of active vehicle at TIME from onboard Encke integration (ft/sec)
RA1X, RA1Y, RA1Z	Components of estimated active vehicle position vector projected into the passive vehicle plane at TCSI (ft)
VA1X, VA1Y, VA1Z	Components of estimated active vehicle velocity vector projected into the passive vehicle plane at TCSI (ft/sec)
RA2X, RA2Y, RA2Z	Components of estimated active vehicle position vector at TCDH (ft)

VA2X, VA2Y, VA2Z	Components of estimated active vehicle velocity vector at TCDH (ft/sec)
RA3X, RA3Y, RA3Z	Components of estimated active vehicle position vector at TTPI (ft)
VA3X, VA3Y, VA3Z	Components of estimated active vehicle velocity vector at TTPI (ft/sec)
UH1X, UH1Y, UH1Z	Components of a unit horizontal vector of active vehicle at TCSI
V1STX, V1STY, V1STZ	Components of active vehicle velocity vector at TCSI after DVCSI is added to VA1 (ft/sec)
UH2X, UH2Y, UH2Z	Components of a unit horizontal vector of active vehicle at TCDH
V2STX, V2STY, V2STZ	Components of estimated active vehicle velocity vector at TCDH after DVCDH is added to VA2 (ft/sec)
UH3X, UH3Y, UH3Z	Components of a unit horizontal vector of active vehicle at TTPI
RP3X, RP3Y, RP3Z	Components of estimated passive vehicle position vector at TTPI (ft)
ECC	Eccentricity of the active vehicle orbit after applying DVCSI
DELV	Velocity increment on DVCSI for iteration purposes (ft/sec)
VPV	Passive vehicle radial velocity at TCDH (ft/sec)
VAV	Active vehicle radial velocity after CDH (ft/sec)
FP1	Central angle between the passive and active vehicle at TCDH; (+) for active vehicle behind passive vehicle (deg)
K	Line-of-sight distance (ft)
GAM	Difference between desired elevation angle at TPI ignition and actual elevation angle when DVCSI iteration is converged
TD2	One-half the active vehicle's orbital period after DVCSI is applied (min)
AA2	Semimajor axis of active vehicle after applying DVCDH (ft)

AP2	Semimajor axis of passive vehicle computed at TCDH (ft)
DT2	Computed time interval between CSI and CDH maneuvers (min)
DT3	Computed time interval between CDH and TPI maneuvers (min)

4.2.6.3 CDH Precomputation Block (output if IPTYPE = 14)

Format

CDH PRECOMPUTATION

TIME	TCDH	TTPI	HCDH	HAP2	PMIN
DVCDH	VAV	VPV	RP2	DELH	ELV
DCDHX	AP2	RPXN	VPXN	RAXN	VAXN
DCDHY	AA2	RPYN	VPYN	RAYN	VAYN
DCDHZ	FP1	RPZN	VPZN	RAZN	VAZN
RA2X	VA2X	RA3X	VA3X	LØSX	DT3
RA2Y	VA2Y	RA3Y	VA3Y	LØSY	DTTPI
RA2Z	VA2Z	RA3Z	VA3Z	LØSZ	
UH2X	V2STX	LØSAN			
UH2Y	V2STY	N			
UH2Z	V2STZ				

Symbol Definitions

(All in ECI unless noted)

TIME	Time of precompute (sec)
TCDH	Time of CDH (sec)
TTPI	Time of TPI estimated by CDH precompute (sec)
HCDH	Altitude of the active vehicle at TCDH (n mi)
HAP2	Altitude of perigee of active vehicle after applying $\underline{\Delta V}_{CDH}$ (n mi)
PMIN	Lower limit on allowable altitude of perigee (n mi)
DVCDH	Magnitude of $\underline{\Delta V}$ required at TCDH (ft/sec)
VAV	Active vehicle radial velocity after CDH (ft/sec)
VPV	Passive vehicle radial velocity at TCDH (ft/sec)
RP2	Passive vehicle position magnitude at TCDH (ft)

DELH	Differential altitude between active and passive vehicle orbits at TCDH, measured along the extension of the active vehicle's position vector (n mi)
ELV	Desired elevation angle at TPI (deg)
DCDHX DCDHY DCDHZ	Components of required $\underline{\Delta V}$ at TCDH in the local vertical coordinate system (ft/sec)
AP2	Semimajor axis of passive vehicle computed at TCDH (ft)
AA2	Semimajor axis of active vehicle after applying $\underline{\Delta V}_{CDH}$ (ft)
FP1	Central angle between the passive and active vehicles at TCDH; (+) for active vehicle behind passive vehicle (deg)
RPXN RPYN RPZN	Components of navigated position vector of passive vehicle at TIME from onboard Encke integration (ft)
VPXN VPYN VPZN	Components of navigated velocity vector of passive vehicle at TIME from onboard Encke integration (ft/sec)
RAXN RAYN RAZN	Components of navigated position vector of active vehicle at TIME from Encke integration (ft)
VAXN VAYN VAZN	Components of navigated velocity vector of active vehicle at TIME from Encke integration (ft/sec)
RA2X RA2Y RA2Z	Components of estimated active vehicle position vector at TCDH (ft)
VA2X VA2Y VA2Z	Components of estimated active vehicle velocity vector at TCDH (ft/sec)
RA3X RA3Y RA3Z	Components of estimated active vehicle position vector at TTPI (ft)
VA3X VA3Y VA3Z	Components of estimated active vehicle velocity vector at TTPI (ft/sec)
LØSX LØSY LØSZ	Line-of-sight vector from estimated active to estimated passive vehicle at TPI time (ft)
DT3	Time interval between calculated TPI time and CDH time (min)
DTTPI	Time interval between TPI time and the specified TPI time (min)

UH2X, UH2Y, UH2Z	Components of a unit horizontal vector of active vehicle at TCDH
V2STX, V2STY, V2STZ	Components of estimated active vehicle velocity vector at TCDH after DVCDH is added to VA2 (ft/sec)
LØSAN	Computed value of elevation angle at TPI (deg)
N	Number of iterations necessary for the convergence of LOSAN to ELV

4.2.6.4 TPI Precomputation Block (output if IPTYPE=15)

Format

TPI PRECOMPUTATION

TIME	TTPIN	TTPI	TTPF	ELV	LØSAN
DVTPI	DVTPF	N	ERR	TERR	ØMEGT
DTPIX	DTPFX	RPXN	VPXN	RAXN	VAXN
DTPIY	DTPFY	RPYN	VPYN	RAYN	VAYN
DTPIZ	DTPFZ	RPZN	VPZN	RAZN	VAZN
RP3X	VP3X	RP4X	VP4X	RAIMX	DELRX
RP3Y	VP3Y	RP4Y	VP4Y	RAIMY	DELRY
RP3Z	VP3Z	RP4Z	VP4Z	RAIMZ	DELRZ
RA3X	VA3X	RTPFX	VTPFX	LØSX	DELR
RA3Y	VA3Y	RTPFY	VTPFY	LØSY	RA3M
RA3Z	VA3Z	RTPFZ	VTPFZ	LØSZ	RP3M
UH3X	VRX	CNANG			
UH3Y	VRY				
UH3Z	VRZ				

Symbol Definitions

(All in ECI unless noted)

TIME	Time of precomputation (sec)
TTPIN	Input nominal time of TPI (sec)
TTPI	Computed value of TPI time corresponding to input elevation angle, E (sec)
TTPF	Time of TPF based on TTPIN and TTPI (sec)

ELV	Desired line-of-sight elevation angle at TTPI measured positive upward from local horizontal in direction of motion (deg)
LØSAN	Computed value of line-of-sight elevation angle at TTPI (deg)
DVTPI	Magnitude of TPI maneuver velocity increment required for intercept trajectory (ft/sec)
DVTPF	Relative velocity magnitude at intercept (ft/sec)
N	Number of iterations required to converge on a TTPI solution
ERR	Elevation angle error (difference between desired and actual value when pre-TPI converges) in computation of TTPI (deg)
TERR	TTPI error due to elevation angle error (sec)
ØMEGT	Central angle formed by passive vehicle between TPF and TPI points (deg)
DTPIX DTPIY DTPIZ	Components of DVTPI (ft/sec)
DTPFX DTPFY DTPFZ	Components of DVTPF (ft/sec)
RPXN RPYN RPZN	Components of navigated position vector of passive vehicle at TIME from onboard Encke integration (ft)
VPXN VPYN VPZN	Components of navigated velocity vector of passive vehicle at TIME from onboard Encke integration (ft/sec)
RAXN RAYN RAZN	Components of navigated position vector of active vehicle at TIME from Encke integration (ft)
VAXN VAYN VAZN	Components of navigated velocity vector of active vehicle at TIME from Encke integration (ft/sec)
RP3X RP3Y RP3Z	Estimated passive vehicle position vector at TTPI (ft)
VP3X VP3Y VP3Z	Estimated passive vehicle velocity vector at TTPI (ft/sec)

RP4X RP4Y RP4Z	Components of estimated passive vehicle position vector at TTPF (ft)
VP4X VP4Y VP4Z	Components of estimated passive vehicle velocity vector at TTPF (ft/sec)
RAIMX RAIMY RAIMZ	Components of converged position aim vector used in Lambert's routine (ft)
DELRX DELRY DELRZ	Components of DELR (ft)
RA3X RA3Y RA3Z	Estimated active vehicle position vector at TTPI (ft)
VA3X VA3Y VA3Z	Estimated active vehicle velocity vector at TTPI (ft/sec)
RTPFX RTPFY RTPFZ	Position vector components of the required state vector at TTPI propagated (Encke precision) to TTPF (ft)
VTPFX VTPFY VTPFZ	Velocity vector components of the required state vector at TTPI propagated (Encke precision) to TTPF (ft/sec)
LØSX LØSY LØSZ	Components of unit vector along line of sight from RA3 to RP3
DELR	Calculated magnitude of position deviation of active vehicle from passive vehicle at TTPF (ft)
RA3M	Magnitude of estimated active vehicle position vector at TTPI (ft)
RP3M	Magnitude of estimated passive vehicle position vector at TTPI (ft)
UH3X UH3Y UH3Z	Components of the unit horizontal vector of the active vehicle at TTPI
VRX VRY VRZ	Components of required velocity at RA3 for intercept at RP4 (ft/sec)
CNANG	The relative central angle between the active and passive vehicle position vectors at TTPI; positive if the active vehicle lags the passive (deg)

4.2.6.5 Midcourse Correction Precomputation Block (output if IPTYPE=16)

Format

MIDCOURSE CORRECTION PRECOMPUTATION

TIME	DTMC	NUMID	TTPF	DVMC	DVTPF
RPXN	VPXN	RAXN	VAXN	DVMCX	DTPFX
RPYN	VPYN	RAYN	VAYN	DVMCY	DTPFY
RPZN	VPZN	RAZN	VAZN	DVMCZ	DTPFZ
RP3X	VP3X	RP4X	VP4X	RAIMX	DELRX
RP3Y	VP3Y	RP4Y	VP4Y	RAIMY	DELRY
RP3Y	VP3Z	RP4Z	VP4Z	RAIMZ	DELRZ
RA3X	VA3X	RTPFX	VTPFX	VRX	RAIM
RA3Y	VA3Y	RTPFY	VTPFY	VRY	DELR
RA3Z	VA3Z	RTPFZ	VTPFZ	VRZ	VR

Symbol Definitions

(All in ECI unless noted)

TIME	Time of midcourse correction precomputation (sec)
DTMC	Desired incremental time of midcourse correction measured from TTPI (sec)
NUMID	Number of midcourse correction
TTPF	Nominal time of TPF (sec)
DVMC	Magnitude of velocity increment required for midcourse correction (ft/sec)
DVTPF	Magnitude of relative velocity at intercept, TTPF (ft/sec)
RPXN, RPYN, RPZN	Components of navigated position vector of passive vehicle at TIME from onboard Encke integration (ft)
VPXN, VPYN, VPZN	Components of navigated velocity vector of passive vehicle at TIME from onboard Encke integration (ft/sec)
RAXN, RAYN, RAZN	Components of navigated position vector of active vehicle at TIME from onboard Encke integration (ft)
VAXN, VAYN, VAZN	Components of navigated velocity vector of active vehicle at TIME from onboard Encke integration (ft/sec)

DVMCX DVMCY DVMCZ	Components of DVMC (ft/sec)
DTPFX DTPFY DTPFZ	Components of DVTPF (ft/sec)
RP3X RP3Y RP3Z	Estimated passive vehicle position vector at time of midcourse (TTPI + DTMC) (ft)
VP3X VP3Y VP3Z	Estimated passive vehicle velocity vector at time of midcourse (TTPI + DTMC) (ft/sec)
RP4X RP4Y RP4Z	Components of estimated passive vehicle position vector at TTPF (ft)
VP4X VP4Y VP4Z	Components of estimated passive vehicle velocity vector at TTPF (ft/sec)
RAIMX RAIMY RAIMZ	Components of converged position aim vector used in Lambert's routine (ft)
DELRX DELRY DELRZ	Components of position deviation of active vehicle from passive vehicle at TTPF (ft)
RA3X RA3Y RA3Z	Estimated active vehicle position vector at time of midcourse (TTPI + DTMC) (ft)
VA3X VA3Y VA3Z	Estimated active vehicle velocity vector at time of midcourse (TTPI + DTMC) (ft/sec)
RTPFX RTPFY RTPFZ	The position vector of the active vehicle state vector at time of midcourse propagated (Encke precision) to TTPF (ft)
VTPFX VTPFY VTPFZ	The velocity vector of the active vehicle state vector at time of midcourse propagated (Encke precision) to TTPF (ft/sec)
VRX VRY VRZ	VR expressed vectorially (ft/sec)
RAIM	Magnitude of position aim vector used in Lambert's routine (ft)

DELR	Calculated magnitude of position deviation of active vehicle from passive vehicle at TTPF (ft)
VR	Magnitude of the required velocity of the active vehicle at time of midcourse for intercept at RP4 (ft/sec)

4.2.6.6 <u>Lambert Aim Point Precomputation Block</u> (output if IPTYPE=17)

<u>Format</u>

LAMBERT AIM POINT PRECOMPUTE

TIME	TLAP	TFØ	NØFFS	RT	RTL
RAXN	VAXN	RA3X	VA3X	RTX	RTLX
RAYN	VAYN	RA3Y	VA3Y	RTY	RTLY
RAZN	VAZN	RA3Z	VA3Z	RTZ	RTLZ
VVG	BBX	VGX	VRX		
VVR	BBY	VGY	VRY		
DTA	BBZ	VGZ	VRZ		

<u>Symbol Definitions</u>

(All in ECI unless noted)

TIME	Time of precompute (sec)
TLAP	Time of ignition for Lambert Aim Point Maneuver (sec)
TFØ	Transfer time from ignition to the target vector (sec)
NØFFS	Number of times input target vector is offset
RT	Magnitude of input target vector (ft)
RTL	Magnitude of offset target vector (ft)
RAXN, RAYN, RAZN	Components of navigated position vector of active vehicle at TIME obtained from onboard Encke integration or from actual state (ft)
VAXN, VAYN, VAZN	Components of navigated velocity vector of active vehicle at TIME obtained from onboard Encke integration or from actual state (ft/sec)
RA3X, RA3Y, RA3Z	Components of estimated active vehicle position vector at TLAP (ft)
VA3X, VA3Y, VA3Z	Components of estimated active vehicle velocity vector at TLAP (ft/sec)

RTX RTY RTZ	Components of input target vector (ft)
RTLX RTLY RTLZ	Components of offset target vector sent to guidance (ft)
VVG	Magnitude of velocity-to-be-gained vector (ft/sec)
VVR	Magnitude of required velocity vector (ft/sec)
DTA	Transfer angle from ignition to the offset target vector (deg)
BBX BBY BBZ	Components of vector, $\underline{b}$, used to compute initial attitude (ft/sec^2)
VGX VGY VGZ	Velocity-to-be-gained vector at TLAP (ft/sec)
VRX VRY VRZ	Required velocity vector at TLAP (ft/sec)

4.2.7 PGNS Ascent Guidance (output if vehicle ID = NVEHT, ITYPE = 7, and PRTG19 = 2.0)

Format

PGNS ASCENT GUIDANCE

TTG	XCM	GEFF	RDT	H	RP
FDAIY	FDAIP	XDGM	XDIR1	XDIR2	XDIR3
AT1	AT2	AT3	ATM	ATR	ATY
B	D	ATH	XDP1	XDP2	XDP3
A	C	ATP	XP1	XP2	XP3
RTI1	RTI2	RTI3	VIR1	VIR2	VIR3
RTJ1	RTJ2	RTJ3	VIY1	VIY2	VIY3
RTK1	RTK2	RTK3	VIZ1	VIZ2	VIZ3
UFDP1	UFDP2	UFDP3	XPD1	XPD2	XPD3
UWDP1	UWDP2	UWDP3	SLR	ECC	YRANG

Symbol Definitions

TTG	Guidance computed time to go to cutoff (sec)
XCM	Ratio of mass-to-mass flow rate (sec)
GEFF	Effective gravity (spherical model) (ft/sec^2)
RDT	Radial velocity computed in guidance until RDT becomes greater than the vertical rise limit. The radial velocity printed out thereafter is the radial rate at which pitchover was initiated. (units of OSCALE)
H	Present altitude above the lunar landing site (units of OSCALE)
RP	Radius of periapsis computed by guidance (units of OSCALE)
FDAIY, FDAIP	Flight direction indicator yaw and pitch angles, respectively (deg)
XDGM	Magnitude of the guidance computed velocity-to-be-gained vector (units of OSCALE)
XDIR1, XDIR2, XDIR3	Velocity-to-be-gained vector in the local vertical coordinate system (radial, crossrange, and downrange, respectively) (units of OSCALE)
AT1, AT2, AT3	The desired thrust acceleration vector in reference body-centered inertial coordinates (ft/sec^2)
ATM	Desired thrust acceleration vector magnitude (ft/sec^2)
ATR	Desired thrust acceleration magnitude in the radial direction (ft/sec^2)
ATY	Desired thrust acceleration magnitude in the out-of-plane direction (ft/sec^2)
B	Guidance parameter which controls the radial position (ft/sec^2)
D	Guidance parameter which controls the out-of-plane position (ft/sec^2)
A	Guidance parameter which controls the radial velocity (units of OSCALE)
C	Guidance parameter which controls the out-of-plane velocity (units of OSCALE)
ATH	Commanded acceleration magnitude in the plane defined by radial and out-of-plane directions (ft/sec^2)
ATP	Commanded thrust acceleration in the downrange direction (ft/sec^2)

XDP1 XDP2 XDP3	Present velocity components in the local vertical coordinate system (radial, crossrange, downrange, respectively) (units of OSCALE)
XP1 XP2 XP3	Present position components in the guidance coordinate system (radial, crossrange, downrange, respectively) (units of OSCALE)
RTI1 RTI2 RTI3	A unit vector directed along the initial radius vector in the reference body-centered inertial (RBCI) coordinate system
RTJ1 RTJ2 RTJ3	A unit vector directed crossrange to the right when viewing in the direction of motion (RBCI coordinate system)
RTK1 RTK2 RTK3	A unit vector directed downrange (in the direction of motion) (RBCI coordinate system)
	NOTE: The vectors $\overline{RTI}$, $\overline{RTJ}$, and $\overline{RTK}$ are orthogonal and make up the guidance coordinate system. (Inertial coordinate system after initial computation)
VIR1 VIR2 VIR3	A unit vector directed along the present radius vector in the reference body-centered inertial coordinate system (RBCI)
VIY1 VIY2 VIY3	A unit vector directed crossrange to the right when viewing in the direction of motion in the (RBCI) coordinate system
VIZ1 VIZ2 VIZ3	A unit vector directed downrange (in the direction of motion) computed as the unit vector of the present radius vector crossed into the RTJ vector of the guidance coordinate system. The resulting vector ($\overline{VIZ}$) is in the RBCI coordinate system.
	NOTE: The vectors $\overline{VIR}$, $\overline{VIY}$, and $\overline{VIZ}$ are orthogonal and make up the local vertical coordinate system (inertial coordinate system over a 2-second compute cycle only)
UFDP1 UFDP2 UFDP3	Unit vector which defines the total commanded thrust direction in the stable member coordinate system. (This coordinate system is necessary for communication with the FINDCDU routine)
XPD1 XPD2 XPD3	Angular momentum vector of the LM orbit in the reference body-centered inertial (RBCI) coordinate system (ft^2/sec)
UWDP1 UWDP2 UWDP3	A desired reference window unit vector in the stable member coordinate system which is used to control the vehicle attitude about the thrust or vehicle X-axis so that the vehicle X-Z place contains the $\overline{UWDP}$ vector.

SLR Semilatus rectum of the present LM orbit (units of OSCALE)

ECC Eccentricity of the present LM orbit

YRANG Desired injection crossrange distance measured from the target plane (units of OSCALE)

4.2.8 Powered Landing Guidance Print Blocks (output if Vehicle ID = NVEHT, ITYPE = 12, and PRTG19 = 2.0)

OUTPUT UNITS:

Controlled by the input GP02,
= 0 Output in ft, ft/sec, lb
= 1 Output in meters, meters/sec, KG

DIAGNOSTICS

No LR data during antenna slew

LR alt. data locked out for 4 sec. after dropout

LR vel. data locked out for 4 sec. after dropout

Landing radar altitude beam read test failed.

Landing radar velocity beam read test failed.

Landing radar altitude reasonableness test failed.

Landing radar velocity reasonableness test failed.

Definitions of Terms

DROPOUT - LR has exceeded its operating boundaries and track has been lost.

READ TEST - Failed if LR unable to obtain a measurement (i.e., beam has missed the moon).

REASONABLENESS TEST - Comparison of LR measurement with an estimate of the acceptable value for that measurement.

4.2.8.1 Powered Landing Guidance Navigation Block

Format

NAVIGATION

T

RNPX	RNPY	RNPZ	VNPX	VNPY	VNPZ
HN	MEST	THEST	RLSPX	RLSPY	RLSPZ

Symbol Definitions

T	Mission time since beginning of run (sec)
RNPX, RNPY, RNPZ	Navigation position of LM at T expressed in PCS (output units of distance)
VNPX, VNPY, VNPZ	Navigation velocity of LM at T expressed in PCS (output units of velocity)
HN	Navigation altitude of LM relative to the estimated radius of the landing site (output units of distance)
MEST	Estimated mass of the LM as determined by the navigation system (output units of weight)
THEST	Estimated thrust of the LM as determined by the navigation system (output units of weight)
RLSPX, RLSPY, RLSPZ	Position of the landing site expressed in PCS (output units of distance)

4.2.8.2 Powered Landing Guidance Landing Radar Block (output if LR is operating and LM is in either breaking, visibility, or final descent phase)

Format

LANDING RADAR

FLRM	RANGM	HM	DELH	SUR	AZBM
FLVM	VCØMP	VM	DELV	IA	IAM

Symbol Definitions

FLRM	Flag set to 1 or 0 according to whether the landing radar (LR) altitude measurement was obtained or not, respectively
RANGM	Slant range as determined by LR (output units of distance)
HM	Projection of RANGM onto local vertical as determined by navigation (output units of distance)
DELH	Difference between landing radar and navigation estimates of altitude (output units of distance)
SUR	Surface range relative to landing site (LS) of point where altitude beam intersects lunar surface
AZBM	Azimuth angle measured from true north of vector from LS to altitude beam intersection with lunar surface (deg)

FLVM	Flag set to 1 or 0 according to whether LR velocity measurement was obtained or not, respectively
VCØMP	Flag set to 1, 2, or 3, according to whether X-, Y-, or Z-antenna component of velocity has been measured, respectively
VM	Measured antenna component of LM velocity relative to lunar surface at beam intersection with surface (output units of velocity)
DELV	Difference between VM and estimated antenna relative velocity component as determined by navigation (output units of velocity)
IA	Angle of incidence of altitude beam (deg)
IAM	Dropout boundary of angle of incidence (deg)

4.2.8.3 Powered Landing Guidance Displays

Format

DISPLAYS

TFI	TGØG	HN	HDØT	DELH	DELVM
VI	VRH	VHF	VHL	RANGE	CR
LPD	NPH				

Symbol Definitions

TFI	Time since DPS ignition (sec)
TGØG	Burn time remaining until the aim-point is reached (sec)
HN	Estimate of LM altitude as determined by navigation (output units of distance)
HDØT	Estimate of LM radial rate as determined by navigation (output units of velocity)
DELH	Difference between landing radar and navigation estimates of altitude (output units of distance)
DELVM	Scalar sum of sensed velocity (output units of velocity)
VI	Magnitude of inertial velocity of LM (output units of velocity)
VRH	Horizontal relative velocity of LM (output units of velocity)
VHF	Forward component of VRH (output units of velocity)
VHL	Lateral component of VRH (output units of velocity)

RANGE	Navigation estimate of slant range to the landing site (output units of distance)
CR	Navigation estimate of crossrange (output units of distance)
LPD	Landing-site elevation angle; complement of angle, measured from LM X-axis to the negative line of sight (deg)
NPH	Guidance phase indicator = 1.0 Preignition = 2.0 Ullage and trim = 3.0 Braking = 4.0 Visibility = 5.0 Vertical descent

4.2.8.4 Powered Landing Guidance Print Block (output if LM is in either breaking, visibility, or final descent phase)

Format

GUIDANCE

TGØG

RNGX	RNGY	RNGZ	VNGX	VNGY	VNGZ
ANGX	ANGY	ANGZ	THD	THC	DELTH
UTDPX	UTDPY	UTDPZ	UWDPX	UWDPY	UWDPZ

Symbol Definitions

TGØG	Burn time remaining until the aim point is reached (sec)
RNGX, RNGY, RNGZ	Navigated position of LM expressed in GCS (output units of distance)
VNGX, VNGY, VNGZ	Navigated velocity of LM expressed in GCS (output units of distance)
ANGX, ANGY, ANGZ	Present desired acceleration of LM expressed in GCS (output units of distance/sec^2)
THD	Desired DPS thrust level (output units of weight)
THC	Commanded throttle level for DPS engine (output units of weight)
DELTH	Commanded increment in thrust required as determined by guidance (output units of weight)

UTDPX UTDPY UTDPZ	Desired thrust direction expressed in PCS
UWDPX UWDPY UWDPZ	Desired window point direction expressed in PCS

4.2.9 Cross Product Steering Block (output if vehicle ID = NVEHT, ITYPE = 13, and PRTG19 = 2.0)

Format

CROSS PRODUCT STEERING

TT	PTIME	TGØ	VVG	DVS	VVR
VGX	DVSX	VVRX	RR	VVN	RRX
VGY	DVSY	VVRY	VV	BB	RRY
VGZ	DVSZ	VVRZ	RRN	DM	RRZ
VVX	RRNX	VVNX	BBX	DMX	GR
VVY	RRNY	VVNY	BBY	DMY	GRN
VVZ	RRNZ	VVNZ	BBZ	DMZ	TF
GRX	GRNX	ØMG	ØMGXE	RTLX	CHIPT
GRY	GRNY	RTL	ØMGYE	RTLY	CHIYT
GRZ	GRNZ	K1	ØMGZE	RTLZ	DVST
UTX	UTY	UTZ			

Symbol Definitions

TT	Evaluation time, referenced to launch time (sec)
PTIME	Phase elapsed time (sec)
TGØ	Time to go to cutoff (sec)
VVG	Magnitude of velocity to be gained (ft/sec)
DVS	Magnitude of sensed velocity change over previous dynamics time interval (ft/sec)
VVR	Magnitude of required velocity (ft/sec)
VGX VGY VGZ	Velocity-to-be-gained vector (ft/sec). This vector is expressed in ECI.

DVSX DVSY DVSZ	Components of DVS (ft/sec)
VVRX VVRY VVRZ	Required velocity vector (ft/sec)
RR	Magnitude of actual position vector (ft)
VV	Magnitude of actual velocity vector (ft/sec)
RRN	Magnitude of navigated position vector from average-g integration (ft)
VVN	Magnitude of navigated velocity vector from average-g integration (ft/sec)
BB	Magnitude of vector, $\underline{b}$ (ft/sec^2)
DM	Magnitude of vector, $\Delta\tilde{m}$ (ft/sec)
RRX RRY RRZ	Components of actual position vector (ft)
VVX VVY VVZ	Components of actual velocity vector (ft/sec)
RRNX RRNY RRNZ	Components of navigated position vector from average-g integration (ft)
VVNX VVNY VVNZ	Components of navigated velocity vector from average-g integration (ft/sec)
BBX BBY BBZ	Components of vector, $\underline{b}$ (ft/sec^2)
DMX DMY DMZ	Components of vector, $\Delta\tilde{m}$ (ft/sec)
GR	Magnitude of actual gravity vector (ft/sec^2)
GRN	Magnitude of navigated gravity vector from average-g (ft/sec^2)
TF	Transfer time input to Lambert's routine to calculate VR (sec)
GRX GRY GRZ	Components of actual gravity vector (ft/sec^2)

GRNX GRNY GRNZ	Components of navigated gravity vector from average-g integration (ft/sec^2)
ØMG	Magnitude of commanded rate of change in thrust vector, $\underline{\omega}_c$ (deg/sec)
RTL	Magnitude of position target vector input to Lambert's routine to calculate VR (ft)
K1	Guidance parameter in time-to-go calculations
ØMGXE ØMGYE ØMGZE	Components of the commanded rate of change in thrust vector in body coordinate system (deg/sec)
RTLX RTLY RTLZ	Components of position target vector input to Lambert targeting routine (if used) to calculate VR (ft)
CHIPT	Commanded pitch angle in the IMU coordinate system measured as the angle between the projection of the commanded thrust vector in the stable member X-Z plane and the stable member X-axis; positive if the projection of the commanded thrust vector on the stable member Z-axis is negative (deg)
CHIYT	Commanded yaw angle in the IMU coordinate system measured as the angle between the commanded thrust vector and its projection in the stable member X-Y plane; positive if the projection of the commanded thrust vector on the stable member Y-axis is positive (deg)
DVST	Accumulated sensed velocity (sum of DVS increments) since initiation of present phase (ft/sec); this accumulator is updated every guidance Δt.
UTX UTY UTZ	Desired unit thrust direction

4.2.10 Abort Guidance System Print Blocks (output if vehicle ID = NVEHT, ITYPE = 20, and PRTG19 = 2.0)

4.2.10.1 AGS Guidance Mode Block

Format

AGS GUIDANCE

PT	DTPER	GTGØ	PP	PPER	PAPØ
PECC	PEA	AT	DQSX	DQSY	DQSZ
RLM	VGMAG	HDØT	VHØR	VYØ	YY
XNA	YNA	ZNA	DXNA	DYNA	DZNA
VGAX	VGAY	VGAZ	LVGX	LVGY	LVGZ
XRC	YRC	ZRC	DXRC	DYRC	DZRC
TE	TCSM	TB	WCX	WCY	WCZ
XBEX	YBEX	ZBEX	XBDX	DVSAX	LDVX
XBEY	YBEY	ZBEY	XBDY	DVSAY	LDVY
XBEZ	YBEZ	ZBEZ	XBDZ	DVSAZ	LDVZ
GNX	GNY	GNZ	HH	MU8	

Symbol Definitions

PT	AGS present time measured from the AGS reference time, T, which is input (sec)
DTPER	Time interval from PT to the time of periapsis assuming no ΔV (sec)
GTGØ	Time to go before guidance cutoff (sec)
PP	Present semilatus rectum (semiparameter) of the LM elliptical orbit (ft)
PPER	Periapsis altitude of the present LM orbit (ft)
PAPØ	Apoapsis altitude of the present LM orbit (ft)
PECC	Eccentricity of the present LM orbit
PEA	Eccentric anomaly of the LM (deg)
AT	Thrust acceleration calculated by the guidance (ft/sec^2)
DQSX, DQSY, DQSZ	Accumulated sensed ΔV in the reference centered inertial coordinate system (ft/sec)
RLM	Magnitude of the present LM navigated position vector (ft)

VGMAG	Magnitude of the velocity-to-be-gained vector (ft/sec)
HDØT	Altitude rate (ft/sec)
VHØR	Horizontal component of the present LM inertial velocity (ft/sec)
VYØ	Component of the present LM velocity in the direction normal to the CSM orbit plane (ft/sec)
YY	Component of the LM inertial position perpendicular to the CSM orbit plane (ft)
XNA YNA ZNA	Present LM navigation position vector calculated in subroutine AGSNAV in reference centered inertial coordinates (ft)
DXNA DYNA DZNA	Present LM navigation velocity vector calculated in subroutine AGSNAV in reference centered inertial coordinates (ft/sec)
VGAX VGAY VGAZ	Velocity-to-be-gained vector in the reference centered inertial coordinate system (ft/sec)
LVGX LVGY LVGZ	Components of the velocity-to-be-gained vector along the LM control P-, U-, and V-axes, respectively. (The numbers which appear in the printout of this vector in the 3-D version will be zeroes. Valid numbers will be printed here when the 6-D simulation is implemented.) (ft/sec)
XRC YRC ZRC	Present CSM position vector as predicted by the closed form f and g series in subroutine ELPRD in the reference centered inertial coordinate system (ft)
DXRC DYRC DZRC	Present CSM velocity vector as predicted by the closed form f and g series in subroutine ELPRD in the reference centered inertial coordinate system (ft/sec)
TE	CSM epoch time referenced to the AGS reference time (sec)
TCSM	CSM orbital period (sec)
TB	Delta time from CSM epoch time to present (sec)
WCX WCY WCZ	Unit angular momentum vector of the CSM orbit in reference centered inertial coordinates
XBEX XBEY XBEZ	Direction cosines of the LM body + X-axis in the reference centered inertial coordinate system
YBEX YBEY YBEZ	Direction cosines of the LM body + Y-axis in the reference centered inertial coordinate system

ZBEX, ZBEY, ZBEZ	Direction cosines of the LM body + Z-axis in the reference centered inertial coordinate system
XBDX, XBDY, XBDZ	Unit vector along the desired point direction
DVSAX, DVSAY, DVSAZ	Sensed velocity increments along the X-, Y-, and Z-axes in the reference centered inertial coordinate system during the most recent 2-second computation cycle (ft/sec)
LDVX, LDVY, LDVZ	Accumulated sensed velocity along the LM body X-, Y-, and Z-axes, respectively. (The numbers which appear in the printout of this vector in the 3-D version will be zeroes. Valid numbers will be printed here when the 6-D simulation is implemented.) (ft/sec)
GNX, GNY, GNZ	Components of the gravity vector in reference centered inertial coordinate system (ft/sec^2)
HH	Present LM altitude (ft)
MU8	Ullage counter. (Number of consecutive 2-second compute cycles with thrust acceleration $a_T \geq$ K435 ft/sec^2 (input before engine on signal is issued) (cycles)

4.2.10.2 AGS Orbit Insertion Block (output if GC006 = 0)

Format

AGS ORBIT INSERTION MODE

PSIP	PSIY	RF	YF	RFDØT	K515
RDDD	YDDD	RJERK	YJERK	VHF	VHA
ASIGN					

Symbol Definition

PSIP	LM desired pitch attitude angle (deg)
PSIY	LM desired yaw attitude angle (deg)
RF	Predicted burnout radius magnitude (ft)
YF	Component of the final LM inertial position vector perpendicular to the transfer orbit plane at burnout (ft)
RFDØT	Predicted final value of the radial rate at orbit insertion (ft/sec)

K515	Lower limit of the desired radial jerk computed as a function of vehicle configuration (ft/sec^3)
RDDD	Desired radial acceleration (ft/sec^2)
YDDD	Desired out-of-plane acceleration (ft/sec^2)
RJERK	Desired radial jerk ($\dddot{r}_d$) (ft/sec^3)
YJERK	Desired out-of-plane jerk ($\dddot{y}_d$) (ft/sec^3)
VHF	Required horizontal component of LM velocity at orbit insertion (ft/sec)
VHA	Component of the LM velocity vector parallel to the CSM orbit plane (ft/sec)
ASIGN	Commanded thrust direction indicator = +1. posigrade = -1. retrograde

4.2.10.3 AGS CSI Block (output if GC006 = 1)

Format

AGS CSI MODE

R5X	R5Y	R5Z	V5X	V5Y	V5Z
R6X	R6Y	R6Z	V6X	V6Y	V6Z
R7X	R7Y	R7Z	V7X	V7Y	V7Z
R5DØT	RCDØT	V2F	THETF	ALPHL	TDEL
VHA	VHF	VPY	J281	J282	J283
RFDØT	DELRP	D6	V55X	V55Y	V55Z
TIGB	TD	B3	TAP	TA	TAØ
TCØ	CØP	VCAPH	VHØ	VPØ	IIØ

Symbol Definitions

R5X R5Y R5Z	Components of estimated position vector of LM at the absolute time of CSI, TIGA (ft)
V5X V5Y V5Z	Components of estimated velocity vector of LM at the absolute time of CSI, TIGA (ft/sec)
R6X R6Y R6Z	Components of estimated position vector of CSM at the time of CDH ignition (ft)

V6X, V6Y, V6Z	Components of estimated velocity vector of CSM at the time of CDH ignition (ft/sec)
R7X, R7Y, R7Z	Components of estimated position vector of the CSM at the line of apsides of the LM orbit (ft)
V7X, V7Y, V7Z	Components of estimated velocity vector of the CSM at the line of apsides of the LM orbit (ft/sec)
R5DØT	Magnitude of the estimated radial velocity of the LM at the time of nominal CSI ignition (ft/sec)
RCDØT	Estimated radial velocity of the CSM at the computed time of CDH ignition (ft/sec)
V2F	Square of the final velocity magnitude required by the LM to achieve a coelliptic orbit (ft^2/sec^2)
THETF	Difference between the central angle of the LM and the CSM at the estimated time of CDH ignition (deg)
ALPHL	Semimajor axis of the LM orbit (ft)
TDEL	Time required for the CSM to move through the angle THETF (sec)
VHA	Horizontal velocity of the LM at the predicted time of ignition of the CDH burn when in the CSI or CDH mode (ft/sec)
VHF	Estimated horizontal component of the velocity of the LM after CDH (ft/sec)
VPY	Out-of-CSM-plane velocity of the LM at the time of ignition of the CSI maneuver (ft/sec)
J281, J282, J283	Components of the external ΔV vector (horizontal, out-of-CSM-plane, and radial, respectively) in the local vertical coordinate system that will be used in the AGS external ΔV routine to steer the CSI burn in the event that VPY is greater than 0.01 (ft/sec) NOTE: The converged value for the horizontal velocity to be gained during the CSI burn is J281.
RFDØT	Radial component of the final velocity required to achieve a coelliptic orbit (ft/sec)
DELRP	Difference between the magnitudes of the estimated radii of the LM and CSM at the time of CDH ignition (ft)
D6	Horizontal velocity search increment (ft/sec)
V55X, V55Y, V55Z	Components of the estimated velocity vector after the CSI maneuver (ft/sec)

TIGB	Time of the CDH maneuver as estimated by the CSI precompute (sec)
TD	Time of CSI ignition (sec)
B3	Central angle between LM and CSM at TPI (deg)
TAP	LM orbital period if S16 = 2; third apsidal crossing for CDH (sec)
TA	Time from nominal CSI to CDH burn (sec)
TAØ	TAØ = TA, corresponding to the best (least) cost function (CØP) for this computing cycle (sec)
TCØ	Predicted time from the CDH burn to TPI, corresponding to the best (least) cost function (COP) for this computing cycle (sec)
CØP	The best (least) cost function for the present compute cycle (the cost function is the difference of the desired and the actual central angle formed by the LM and the CSM at TPI) (deg)
VCAPH	Magnitude of the velocity (horizontal) increment parallel to the CSM orbit plane to be added in the CSI burn. (This value corresponds to the value obtained in the final iteration through the cost function evaluation loop.)
VHØ	Horizontal component of the predicted final CSI velocity corresponding to the best (least) cost function for this computing cycle (ft/sec)
VPØ	VPØ = VG, the predicted velocity to be gained at CDH corresponding to the best (least) cost function for this computing cycle (ft/sec)
IIØ	Iteration counter value corresponding to the best (least) cost function for this computing cycle (the counter in the program is called II and has the values of -1, 0, +1 for the 1st, 2nd, or 3rd iterations, respectively). The value of II is loaded into IIØ on the iteration which yields the best (least) cost function.

4.2.10.4 AGS CDH Block (output if GC006 = 2)

Format

AGS CDH MODE

R6X	R6Y	R6Z	V6X	V6Y	V6Z
R7X	R7Y	R7Z	V7X	V7Y	V7Z
R5DØT	RCDØT	V2F	THETF	ALPHL	TDEL
VHA	VHF	VPY	J281	J282	J283

Symbol Definitions

R6X, R6Y, R6Z	Components of estimated position vector of LM at the time of CDH ignition (ft)
V6X, V6Y, V6Z	Components of estimated velocity vector of LM at the time of CDH ignition (ft/sec)
R7X, R7Y, R7Z	Components of estimated position vector of the CSM at the line of apsides of the LM orbit (ft)
V7X, V7Y, V7Z	Components of estimated velocity vector of the CSM at the line of apsides of the LM orbit (ft/sec)
R5DØT	Magnitude of predicted radial velocity of the LM at the time of CDH (ft/sec)
RCDØT	Radial velocity of the CSM at the predicted time of the CDH burn (ft/sec)
V2F	Square of the final velocity magnitude required by the LM to achieve a coelliptic orbit (ft^2/sec^2)
THETF	Difference between the central angle of the LM and the CSM at the estimated time of CDH ignition (deg)
ALPHL	Semimajor axis of the LM orbit (ft)
TDEL	Time required for the CSM to move through the angle THETF (sec)
VHA	Horizontal velocity of the LM at the predicted time of ignition of the CDH burn when in the CSI or CDH mode (ft/sec)
VHF	Estimated horizontal component of the velocity of the LM after CDH (ft/sec)
VPY	Out-of-CSM-plane velocity of the LM at the time of ignition of the CDH maneuver (ft/sec)
J281, J282, J283	Components of the external ΔV vector (horizontal, out-of-CSM-plane, and radial, respectively) in the local vertical coordinate system that will be used in the AGS external ΔV routine to steer the CSI burn in the event that VPY is greater than 0.01 (ft/sec)

4.2.10.5 AGS TPI Block (output if GC006 = 3 or 4)

Format

AGS TPI MODE

TIGC	TD	P	RRX	RRY	RRZ
TLØS	RX	RZ	RFDØT	TR	T
R8X	R8Y	R8Z	V8X	V8Y	V8Z
RTX	RTY	RTZ	VTX	VTY	VTZ
C1	C2	E2	RIDTX	RIDTY	RIDTZ
RFDTX	RFDTY	RFDTZ	VFMAG	VTMAG	Q1D
VFX	VFY	VFZ	W1X	W1Y	W1Z
VGØ	TRØ	TLØSØ	VTØ	Q1Ø	TIGCØ

Symbol Definitions

TIGC — The absolute time of TPI ignition measured from AGS reference time (sec). In the targeting or precompute TPI mode, this value will be equal to AGS present time (PT) plus a time increment (TD); therefore, TIGC is updated by 2 seconds every compute cycle. In the TPI execute mode, this value is input (GC080) either by the user or transferred from the precompute phase.

TD — Time increment from present guidance time to the time of ignition for the TPI maneuver (sec)

P — Semiparameter of the LM transfer orbit (ft)

RRX, RRY, RRZ — Predicted relative position vector of CSM with respect to the LM at TPI time in reference body centered inertial coordinates (ft)

TLØS — Angle between the LM-CSM line of sight (LOD) and the LM local horizontal at the desired TPI time measured clockwise from the local horizontal oriented positive in the direction of motion (deg)

RX — Component of the vector (RRX, RRY, RRZ) along the unit radius vector of the LM at the time of TPI

RZ — Component of the vector (RRX, RRY, RRZ) along the vector $\overline{V}_1$ at the time of TPI, where $\overline{V}_1$ is computed as follows:

$$\overline{V}_1{}' = \left[\overline{UR} \times \left(\frac{\overline{W}_c \times \overline{UR}}{|\overline{W}_c \times \overline{UR}|}\right)\right] \times \overline{U}_1$$

$$\bar{V}_1 = \frac{\bar{V}_1'}{|\bar{V}_1'|}$$

	$\overline{UR}$ is the unit present LM radius vector
	$\bar{W}_c$ is the unit angular momentum vector of the CSM orbit
	$\bar{U}_1$ is the unit radius vector of the LM at the time of TPI
RFDØT	LM radial velocity after first impulse (of the two impulses) for transfer orbit (ft/sec)
TR	Instantaneous predicted time to rendezvous (sec)
T	Predicted time from TPI to rendezvous (sec)
R8X, R8Y, R8Z, V8X, V8Y, V8Z	Predicted LM inertial position and velocity vector, respectively, at TIGC, the desired time of TPI (ft, ft/sec)
RTX, RTY, RTZ, VTX, VTY, VTZ	Predicted CSM inertial position and velocity vector, respectively, at J4 seconds prior to rendezvous where J4 is the input time of the node prior to rendezvous (ft, ft/sec)
C1 C2	The cosine and sine, respectively, of the central angle between the instantaneous LM position vector and the CSM position vector at J4 seconds prior to rendezvous
E2	Eccentricity (squared) of the transfer orbit
RIDTX, RIDTY, RIDTZ	LM velocity vector after the first impulse (of the two impulses) for the transfer orbit (ft/sec)
RFDTX, RFDTY, RFDTZ	LM velocity vector just prior to the second impulse in the transfer orbit (ft/sec)
VFMAG	Magnitude of the predicted braking velocity vector (ft/sec)
VTMAG	Total velocity required to rendezvous (ft/sec)
Q1D	LM transfer orbit periapsis altitude (ft)
VFX VFY VFZ	Predicted braking velocity vector (ft/sec)

W1X, W1Y, W1Z	Unit vector perpendicular to the transfer orbit plane

NOTE: The parameters in the last line of this block are printed as zeroes unless the user chooses the option requiring the TPI precompute to converge on the minimum velocity-to-be-gained value. This option is specified by the input GP02 = 1. The parameters are defined as follows:

VGØ	The minimum value of velocity to be gained (VGMAG) for TPI computed during the TPI burn (ft/sec)
TRØ	The value of TR corresponding to VGØ (sec)
TLØSØ	The value of TLØS corresponding to VGØ (deg)
VTØ	The magnitude of (VTX, VTY, VTZ) corresponding to VGØ (ft/sec)
Q1Ø	The value of Q1D corresponding to VGØ (ft)
TIGCØ	The value of TIGC corresponding to VGØ (sec)

4.2.10.6 AGS External Delta-V Block (output if GC006 = 5)

Format

AGS EXTERNAL DELTA V MODE

XDVX	XDVY	XDVZ	J281	J282	J283
S07					

Symbol Definitions

XDVX, XDVY, XDVZ	Total ΔV vector for the burn in the reference body-centered inertial coordinate system (ft/sec)
J281	Horizontal velocity to be gained (ft/sec)
J282	Out-of-CSM-plane velocity to be gained (ft/sec)
J283	Radial velocity to be gained (ft/sec)

S07	= 0	External delta V vector set up as $\overline{\Delta V} = -J283\overline{U}_1 + J281\overline{V}_1 - J282\overline{W}_1$, where $\overline{U}_1$ = unitized present LM radius vector, $\overline{V}_1$ = unit vector directed downrange from the LM parallel to the CSM orbit plane, and $\overline{W}_1$ = unit vector given by $\overline{U}_1 \times \overline{V}_1$, i.e., normal to the CSM plane (sensed velocity increment set to zero)
	= 1	External ΔV vector fixed in the reference body-centered inertial coordinate system (sensed velocity increments allowed to accumulate)

4.2.11 Guidance Dynamics Block (output if vehicle ID = NVEHT and PRTG20 = 2.0)

Format

GUIDANCE DYNAMICS

TT	WDØT	ISP	TNAV	WT	FFF
RRX	RRXN	VVX	VVXN	VMASS	FACC
RRY	RRYN	VVY	VVYN	GGG	DACC
RRZ	RRZN	VVZ	VVZN	PTCHR	YAWR
FACCX	DACCX	GX	XBXSM	IAAP	VLSGX
FACCY	DACCY	GY	XBYSM	IAAY	VLSGY
FACCZ	DACCZ	GZ	XBZSM	IAAT	VLSGZ
RR	AZMTH	SMAJ	APERI	TANØM	PERØD
VV	DECLN	ECCEN	NODE	HPERI	ENRGY
GAM	ASCEN	INCL	MANØM	HAPØ	AGMØM
IGANG	XBX	YBX	ZBX	H	TPTCH
MGANG	XBY	YBY	ZBY	GMBLP	TYAW
ØGANG	XBZ	YBZ	ZBZ	GMBLY	RBØDY

(If ITYPE = 13)

DVPR1	DVPMG	DVER1	ERRMG	DPTCH
DVPR2	DVPT	DVER2	DVP	DYAW
DVPR3	DVYT	DVER3	DVY	DVEFF

Symbol Definitions

TT	Dynamics evaluation time (sec)
WDØT	Mass flow rate (lb/sec)
ISP	Specific impulse (sec)
TNAV	Time of last navigation update, referenced to launch time (hr)
WT	Instantaneous vehicle weight (lb)
FFF	Thrust magnitude (lb)
RRX RRY RRZ	Components of vehicle actual position vector (ft)
RRXN RRYN RRZN	Components of vehicle navigation position vector (ft)
VVX VVY VVZ	Components of vehicle actual velocity vector (ft/sec)
VVXN VVYN VVZN	Components of vehicle navigation velocity vector (ft/sec)
VMASS	Instantaneous vehicle mass (slug)
GGG	Magnitude of the total gravitational acceleration used in the Cowell scheme or perturbative acceleration used by the Encke scheme (ft/sec^2)
PTCHR	Rate of change of pitch command about the vehicle's Y-axis, positive in the right-handed sense (deg/sec)
FACC	Magnitude of the acceleration due to thrust (ft/sec^2)
DACC	Magnitude of the acceleration due to drag (ft/sec^2)
YAWR	Rate of change of yaw command about the vehicle's Z-axis, positive in the right-handed sense (deg/sec)
FACCX FACCY FACCZ	Components of FACC (ft/sec^2)
DACCX DACCY DACCZ	Components of DACC (ft/sec^2)
GX GY GZ	Components of GGG (ft/sec^2)

XBXSM XBYSM XBZSM	Direction cosines of the body X-axis relative to the stable member (SM) coordinate system
IAAP (AAAP)	Pitch angle of attack* with respect to the inertial (relative) velocity vector (deg)
IAAY (AAAY)	Yaw angle of attack* with respect to the inertial (relative) velocity vector (deg)
IAAT (AAAT)	Total angle of attack* with respect to the inertial (relative) velocity vector (deg)
VLSGX VLSGY VLSGZ	ECI components of the velocity loss due to gravity since beginning of thrust (ft/sec) (initialized, phase by phase)
RR	Radius vector magnitude (ft)
VV	Inertial velocity vector magnitude (ft/sec)
GAM	Flight-path angle* measured positive upward from the local horizontal to the inertial velocity vector (deg)
AZMTH	Angle* measured in horizontal plane between the projection of the inertial velocity vector onto the plane and the north direction; positive eastward (deg)
DECLN	Declination* of the vehicle measured from the equatorial plane to the position vector of the vehicle; positive in the northern hemisphere (deg)
ASCEN	Right ascension* measured from the vernal equinox; eastward in the equatorial plane to the meridian plane that contains the vehicle (deg)
SMAJ	Semimajor axis* of instantaneous Keplerian conic (ft)
ECCEN	Eccentricity*
INCL	Inclination* of the vehicle orbital plane to the reference body equatorial plane (deg)
APERI	Argument of perigee* measured from the ascending node to perigee in the conic plane (deg)
NØDE	Right ascension* of the ascending node measured positive eastward in the equatorial plane from the vernal equinox (deg)
MANØM	Mean anomaly* (deg)
TANØM	True anomaly* (deg)
HPERI	Periapsis altitude*, based on the value of RBODY (n mi)

*Based on the actual state vector

HAPØ	Apoapsis altitude*, based on the value of RBØDY (n mi)
PERØD	Orbital period* (min)
ENRGY	Orbital energy* (ft^2/sec^2)
AGMØM	Twice the angular momentum* (ft^2/sec)
IGANG	Inner (pitch) platform gimbal angle (deg)
MGANG	Middle (yaw) platform gimbal angle (deg)
ØGANG	Outer (roll) platform gimbal angle (deg)
XBX XBY XBZ	Components of a unit vector along the vehicle X-axis in the ECI system
YBX YBY YBZ	Components of a unit vector along the vehicle Y-axis in the ECI system
ZBX ZBY ZBZ	Components of a unit vector along the vehicle Z-axis in the ECI system
H	Altitude* above the surface of the reference body, RBODY, along the radius vector (ft)
GMBLP GMBLY	Pitch and yaw engine gimbal angles which would be required to direct the main engine thrust vector through the vehicle's total center of gravity (deg)
TPTCH	The angle* between the thrust acceleration vector and the local horizontal plane positive upwards (deg)
TYAW	Azimuth* of the projection of the thrust acceleration vector in the horizontal plane with respect to the projection of the inertial velocity into the local horizontal (deg)
RBØDY	Spherical body radius used in computation of HPERI, HAPØ, and H (ft). The value appearing for this variable is a function of the input INJECT, that is, if INJECT $\leq$ 19, then RBØDY = 20,909,901. ft if INJECT $\geq$ 20, then RBØDY = 5,702,395.0 ft
DVPR1 DVPR2 DVPR3	Components of the cross-axis portion of sensed velocity over the previous guidance Δt (ft/sec)
DVPMG	Magnitude of the cross-axis portion of sensed velocity over the previous guidance Δt (ft/sec)
DVPT	Accumulated pitch portion of cross-axis velocity since initiation of phase; the sum of DVP (ft/sec)

*Based on the actual state vector

DVYT	Accumulated yaw portion of cross-axis velocity since initiation of phase; the sum of DVY (ft/sec)
DVER1, DVER2, DVER3	Components of the accumulated cross-axis portion of sensed velocity since phase initiation (ft/sec)
ERRMG	Magnitude of the accumulated cross-axis portion of sensed velocity since phase initiation (ft/sec)
DVP	Pitch component of the cross-axis portion of sensed velocity over the previous guidance Δt (ft/sec)
DVY	Yaw component of the cross-axis portion of sensed velocity over the previous guidance Δt (ft/sec)
DPTCH	Sensed velocity pitch angle, measured in the positive sense from the X-axis upward to the projection of the sensed velocity into the X-Z plane (deg)
DYAW	Sensed velocity yaw angle, measured from the X-axis to the projection of the sensed velocity in the X-Y plane (positive from +X toward +Y) (deg)
DVEFF	Component of the sensed velocity vector (over the previous guidance Δt) which lies along the velocity-to-be-gained vector as defined at main ignition (ft/sec)

4.2.12 LM Guidance - Digital Autopilot Interface (output if vehicle ID = NVEHT, ITYPE = 7, 12, or 13, and PRTG27 = 2.0)

Format

GUIDANCE - DAP INTERFACE

ØGADD	XBDPX	ØGADG	DØGAD	DØGAC	ØMDVX
IGADD	XBDPY	IGADG	DIGAD	DIGAC	ØMDVY
MGADD	XBDPZ	MGADG	DMGAD	DMGAC	ØMDVZ
FLAX	DAPLX	DAPLY	DAPLZ		

Symbol Definitions

ØGADD, IGADD, MGADD	Desired outer, inner, and middle gimbal angles as known by the DAP at the time that the interface routine is entered (deg)
XBDPX, XBDPY, XBDPZ	Desired vehicle X-axis expressed in the platform coordinate system

ØGADG, IGADG, MGADG	Desired, unlimited outer, inner, and middle gimbal angles computed by the interface routine (deg)
DØGAD, DIGAD, DMGAD	Desired change in outer, inner, and middle gimbal angles to be executed over the guidance cycle time (deg)
DØGAC, DIGAC, DMGAC	Commanded change in outer, inner, and middle gimbal angles to be executed over the DAP cycle time (deg)
ØMDVX, ØMDVY, ØMDVZ	Desired vehicle angular rate expressed in the desired vehicle coordinate system (deg/sec)
FLAX	Yaw-control mode flag set to 1 or 0 according to whether automatic yaw steering is to be used or not, respectively
DAPLX, DAPLY, DAPLZ	Attitude-error lead angle required by the DAP expressed in the desired vehicle coordinate system (deg)

4.2.13 RTCC Parameters (output if NV = 2, the vehicle ID = NVEHT, ITYPE = 7, 12, 13, or 20, and PRTG28 = 2.0)

NOTE: If JNAV = 0, the AGS navigated state is equal to the actual state.

4.2.13.1 RTCC Onboard Print Block

Format

RTCC ONBOARD DISPLAY

HTAP	HDTAP	TWIND			
HA	HDA	ØØPDA	ØØPVA	RNGA	RNGRA
HP	HDP	ØØPDP	ØØPVP	RNGP	RNGRP
AFDR	AFDP	AFDY	PFDR	PFDP	PFDY

Symbol Definitions

HTAP	LM tapemeter value of altitude when driven by the LR (units of OSCALE)
HDTAP	LM tapemeter value of altitude rate when driven by the LR (units of OSCALE)
TWIND	Thrust/weight indicator onboard the LM. LM X-axis (body) acceleration in lunar g's.

HA	LM altitude with respect to the landing site as computed by the AGS navigated state (units of OSCALE)
HDA	LM altitude rate as computed by the AGS navigated state (units of OSCALE)
ØØPDA	LM out-of-plane distance from the CSM orbit plane as computed by the AGS navigated state (units of OSCALE)
ØØPVA	LM out-of-plane velocity. Computed as velocity along LM body Y-axis as determined by AGS navigated state (units of OSCALE)
RNGA	LM/CSM range as computed by the AGS navigated state (units of OSCALE)
RNGRA	LM/CSM range rate as computed by the AGS navigated state (units of OSCALE)
HP	LM altitude with respect to the landing site as computed by the PGNS navigated state (units of OSCALE)
HDP	LM altitude rate as computed by the PGNS navigated state (units of OSCALE)
ØØPDP	LM out-of-plane distance from the CSM orbit plane as computed by the PGNS navigated state (units of OSCALE)
ØØPVP	LM out-of-plane velocity. Computed as velocity along LM body Y-axis as determined by PGNS navigated state (units of OSCALE)
RNGP	LM/CSM range as computed by the PGNS navigated state (units of OSCALE)
RNGRP	LM/CSM range rate as computed by the PGNS navigated state (units of OSCALE)
AFDR	Flight direction indicator roll angle as computed by AGS navigated state (deg)
AFDP	Flight direction indicator pitch angle as computed by AGS navigated state (deg)
AFDY	Flight direction indicator yaw angle as computed by AGS navigated state (deg)
PFDR	Flight direction indicator roll angle as computed by PGNS navigated state (deg)
PFDP	Flight direction indicator pitch angle as computed by PGNS navigated state (deg)
PFDY	Flight direction indicator yaw angle as computed by PGNS navigated state (deg)

4.2.13.2 RTCC Ground Print Block

Format

RTCC GROUND DISPLAYS

DHTAP	DVTAP	RGØ	DHLRA	DHLRP	DHLRM
DVAPX	DVAPY	DVAPZ	DVLPX	DVLPY	DVLPZ
DELTA	YDØT	PITCH	YAW		

Symbol Definitions

DHTAP	Total difference between AGS and PGNS altitude (units of OSCALE)
DVTAP	Difference between AGS and PGNS inertial velocity vector magnitudes (units of OSCALE)
RGØ	Range to go to final radius vector, landing site for descent (ITYPE = 12), insertion for ascent (ITYPE = 7), CSM position for powered flight (ITYPE = 13). (units of OSCALE)
DHLRA	Difference between LR and AGS altitude (units of OSCALE)
DHLRP	Difference between LR and PGNS altitude (units of OSCALE)
DHLRM	Difference between LR and MSFN altitude (units of OSCALE)
DVAPX DVAPY DVAPZ	Difference between AGS and PGNS inertial velocity vectors in LCS (units of OSCALE)
DVLPX DVLPY DVLPZ	Difference between LR and PGNS velocity in antenna coordinate system (units of OSCALE)
DELTA	Angle between the instantaneous LM navigated orbit plane and a plane containing the landing site whose inclination is equal to the selenographic latitude of the landing site (deg)
YDØT	Descent (ITYPE = 12) PGNS navigated velocity normal to a plane defined by present position and landing site vectors Ascent (ITYPE = 7) PGNS navigated velocity normal to the instantaneous CSM orbit plane (units of OSCALE)
PITCH	Pitch angle in LCS (deg)
YAW	Yaw angle in LCS (deg)

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